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HSWA LANL G/P '98

FEB 1998
RECEIVED

Date: February 20, 1998
Refer to: EM/ER:98-050

Mr. Benito Garcia
NMED-HRMB
P.O. Box 26110
Santa Fe, NM 87502

SUBJECT: ANNUAL WORK SCHEDULE FOR THE 1996 INSTALLATION WORK PLAN

Dear Mr. Garcia:

Enclosed please find Los Alamos National Laboratory's Annual Work Schedule for the 1996 Installation Work Plan (IWP). The format and content of this schedule has been agreed upon with members of your staff.

Should you have any questions, please contact Dave McInroy at (505) 667-0819 or Joe Mose at (505) 667-5808.

Sincerely,

Julie A. Canepa, Program Manager
LANL/ER Project

Sincerely,

Theodore J. Taylor, Program Manager
DOE/LAAO

JC/TT/kr

15684

Enclosure: LANL Annual Work Schedule for the 1996 Installation Work Plan.

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FY 97 Schedule*

SWMU NO.	SITE TYPE	WASTE TYPE	VOLUME	POTENTIAL CONTAMINANTS	POTENTIAL REMEDIAL ACTION	SITE RANKING SCORE	AP 4.5 SCORE	WORK SCHEDULED	ANTICIPATED FIELD START	REPORT DATE
0-003	Above Ground Material/ Waste	Not Applicable	Not Applicable	None	NFA RFI Rpt	26	TBD	Characterization	12/1/96	9/30/97
0-012	Tanks (Underground Storage)	Not Applicable	Not Applicable	None	NFA RFI Rpt	36	TBD	Characterization	12/1/96	9/30/97
0-016	Firing Ranges/Ordnance	Haz, non-Haz	555cyd/ 900,000g	Haz	VCA	44	17.5	Remediation	10/1/96	9/29/97
0-018(a)	Buildings/Equipment	Not Applicable	Not Applicable	Rad, Haz	NFA RFI Rpt	49	42.8	Characterization	12/1/96	9/12/97
1-001(s)	Buildings/Equipment	Not Applicable	Not Applicable	Rad, Haz	NFA RFI Rpt	None	3.6	Characterization	1/1/97	9/30/97
1-001(u)	Buildings/Equipment	Not Applicable	Not Applicable	None	NFA RFI Rpt	None	TBD	Characterization	1/1/97	9/30/97
1-007(l)	Spills and Leaks	Not Applicable	Not Applicable	Rad	NFA RFI Rpt	25	3.6	Characterization	1/1/97	9/30/97
3-014(k)	Buildings/Equipment	Not Applicable	Not Applicable	Haz	NFA RFI Rpt	None	TBD	Characterization	6/1/97	9/30/97
3-014(l)	Buildings/Equipment	Not Applicable	Not Applicable	Haz	NFA RFI Rpt	47	TBD	Characterization	6/1/97	9/30/97
3-014(o)	Buildings/Equipment	Not Applicable	Not Applicable	Haz	NFA RFI Rpt	47	TBD	Characterization	7/1/97	9/30/97
3-021	Surface/ Subsurface Material/ Waste	Not Applicable	Not Applicable	Haz	NFA RFI Rpt	26	39.8	Characterization	7/1/97	9/30/97
3-049(a)	Surface/ Subsurface Material/ Waste	Not Applicable	Not Applicable	Haz	NFA RFI Rpt	None	36.8	Characterization	7/1/97	9/30/97
3-054(e)	Surface/ Subsurface Material/ Waste	Not Applicable	Not Applicable	Haz	NFA RFI Rpt	40	85.0	Characterization	6/1/97	9/30/97
6-001(a)	Buildings/Equipment	Not Applicable	Not Applicable	Rad, Haz	NFA RFI Rpt	40	3.6	Report		9/29/97
6-001(b)	Buildings/Equipment	Not Applicable	Not Applicable	Rad, Haz	NFA RFI Rpt	40	3.6	Report		9/29/97
6-003(a)	Firing Ranges/Ordnance	Not Applicable	Not Applicable	Rad, Haz	NFA RFI Rpt	40	3.6	Report		9/29/97
6-003(c)	Firing Ranges/Ordnance	Not Applicable	Not Applicable	Rad, Haz	NFA RFI Rpt	40	3.6	Report		9/29/97
6-003(f)	Firing Ranges/Ordnance	Not Applicable	Not Applicable	Rad, Haz	NFA RFI Rpt	40	TBD	Report		9/29/97
6-003(g)	Firing Ranges/Ordnance	Not Applicable	Not Applicable	Haz, HE	NFA RFI Rpt	40	TBD	Report		9/29/97
6-007(g)	Surface/ Subsurface Material/ Waste	Not Applicable	Not Applicable	Rad, Haz	NFA RFI Rpt	40	TBD	Report		9/29/97
7-001(a)	Firing Ranges/Ordnance	Not Applicable	Not Applicable	Haz, HE	NFA RFI Rpt	40	TBD	Report		9/29/97

FY 97 Schedule*

SWMU NO.	SITE TYPE	WASTE TYPE	VOLUME	POTENTIAL CONTAMINANTS	POTENTIAL REMEDIAL ACTION	SITE RANKING SCORE	AP 4.5 SCORE	WORK SCHEDULED	ANTICIPATED FIELD START	REPORT DATE
7-001(b)	Firing Ranges/Ordnance	Not Applicable	Not Applicable	Haz, HE	NFA RFI Rpt	40	TBD	Report		9/29/97
7-001(c)	Firing Ranges/Ordnance	Not Applicable	Not Applicable	Haz, HE	NFA RFI Rpt	40	TBD	Report		9/29/97
7-001(d)	Firing Ranges/Ordnance	Not Applicable	Not Applicable	Haz, HE	NFA RFI Rpt	40	TBD	Report		9/29/97
8-002	Firing Ranges/Ordnance	Not Applicable	Not Applicable	Rad, Haz	NFA RFI Rpt	40	TBD	Report		9/29/97
13-003(a)	Tanks (Septic, Above Ground)	Not Applicable	Not Applicable	Rad, Haz, HE	NFA RFI Rpt	18	TBD	Characterization	6/1/97	9/30/97
14-003	Surface/ Subsurface Material/ Waste	Haz, non-Haz, Mixed	5 cyd/ 11cyd/ 3 cyd/	Rad, Haz	VCA	26	31.4	Remediation	4/1/97	9/29/97
16-006(c)	Buildings/Equipment	Not Applicable	Not Applicable	Rad, Haz	NFA RFI Rpt	21	49.5	Characterization	7/1/97	9/30/97
16-006(d)	Buildings/Equipment	Not Applicable	Not Applicable	Rad, Haz, HE	NFA RFI Rpt	22	TBD	Characterization	7/1/97	9/30/97
16-010(a)	Surface/ Subsurface Material/ Waste	Not Applicable	Not Applicable	Haz, HE	NFA RFI Rpt	65	38.4	Characterization	7/1/97	9/30/97
16-013	Above Ground Material/ Waste	Not Applicable	Not Applicable	Rad, Haz	NFA RFI Rpt	28	22.7	Characterization	4/1/97	9/26/97
16-021(a)	Spills and Leaks	Not Applicable	Not Applicable	Haz	NFA RFI Rpt	26	27.5	Characterization	10/1/96	9/30/97
16-025(b2)	Buildings/Equipment	Not Applicable	Not Applicable	Haz	NFA RFI Rpt	38	3.6	Characterization	7/1/97	9/30/97
16-025(d)	Buildings/Equipment	Not Applicable	Not Applicable	Haz, HE	NFA RFI Rpt	42	8.8	Characterization	7/1/97	9/30/97
16-025(g)	Buildings/Equipment	Not Applicable	Not Applicable	Haz, HE	NFA RFI Rpt	42	8.8	Characterization	7/1/97	9/30/97
16-025(j)	Buildings/Equipment	Not Applicable	Not Applicable	Haz, HE	NFA RFI Rpt	42	8.8	Characterization	7/1/97	9/30/97
16-025(k)	Buildings/Equipment	Not Applicable	Not Applicable	Haz, HE	NFA RFI Rpt	38	10.5	Characterization	7/1/97	9/30/97
16-025(m)	Buildings/Equipment	Not Applicable	Not Applicable	Rad, Haz, HE	NFA RFI Rpt	36	8.8	Characterization	7/1/97	9/30/97
16-025(n)	Buildings/Equipment	Not Applicable	Not Applicable	Rad, Haz, HE	NFA RFI Rpt	36	8.8	Characterization	7/1/97	9/30/97
16-025(o)	Buildings/Equipment	Not Applicable	Not Applicable	Rad, Haz, HE	NFA RFI Rpt	36	8.8	Characterization	7/1/97	9/30/97
16-025(x)	Buildings/Equipment	Not Applicable	Not Applicable	Haz, HE	NFA RFI Rpt	47	3.6	Characterization	4/1/97	9/26/97
16-025(y)	Buildings/Equipment	Not Applicable	Not Applicable	Haz, HE	NFA RFI Rpt	35	22.3	Characterization	7/1/97	9/30/97

FY 97 Schedule*

SWMU NO.	SITE TYPE	WASTE TYPE	VOLUME	POTENTIAL CONTAMINANTS	POTENTIAL REMEDIAL ACTION	SITE RANKING SCORE	AP 4.5 SCORE	WORK SCHEDULED	ANTICIPATED FIELD START	REPORT DATE
16-026(c)	Surface/ Subsurface Material/ Waste	Not Applicable	Not Applicable	Haz	NFA RFI Rpt	39	10.6	Characterization	7/1/97	9/30/97
16-026(d)	Surface/ Subsurface Material/ Waste	Not Applicable	Not Applicable	Haz, HE	NFA RFI Rpt	39	10.6	Characterization	7/1/97	9/30/97
16-026(v)	Surface/ Subsurface Material/ Waste	Not Applicable	Not Applicable	Haz	NFA RFI Rpt	33	61.8	Characterization	7/1/97	9/30/97
16-028(a)	Buildings/Equipment	Not Applicable	Not Applicable	None	NFA RFI Rpt	65	TBD	Characterization	7/1/97	9/30/97
16-031(d)	Buildings/Equipment	Not Applicable	Not Applicable	Haz	NFA RFI Rpt	38	10.5	Characterization	4/1/97	9/26/97
16-034(c)	Spills and Leaks	Not Applicable	Not Applicable	Haz, HE	NFA RFI Rpt	36	19.7	Characterization	7/1/97	9/30/97
16-034(d)	Spills and Leaks	Not Applicable	Not Applicable	Haz, HE	NFA RFI Rpt	36	19.7	Characterization	7/1/97	9/30/97
16-034(e)	Spills and Leaks	Not Applicable	Not Applicable	Haz, HE	NFA RFI Rpt	36	19.7	Characterization	7/1/97	9/30/97
16-034(f)	Spills and Leaks	Not Applicable	Not Applicable	Rad, Haz, HE	NFA RFI Rpt	36	19.7	Characterization	7/1/97	9/30/97
16-034(l)	Spills and Leaks	Not Applicable	Not Applicable	Haz, HE	NFA RFI Rpt	38	3.6	Characterization	7/1/97	9/30/97
16-034(m)	Spills and Leaks	Not Applicable	Not Applicable	Haz, HE	NFA RFI Rpt	35	22.3	Characterization	7/1/97	9/30/97
19-001	Buildings/Equipment	Not Applicable	Not Applicable	Haz	NFA RFI Rpt	35	8.8	Characterization	1/1/97	9/30/97
19-003	Tanks (Septic, Above Ground)	Not Applicable	Not Applicable	None	NFA RFI Rpt	39	8.8	Characterization	1/1/97	9/30/97
21-011(k)	Trenches/Outfalls	Not Applicable	Not Applicable	Rad, Haz	VCA	67	72.0	Interim Action or Stabilization	10/1/96	IA Rpt 4/3/97
21-013(a)	Surface/ Subsurface Material/ Waste	Not Applicable	Not Applicable	Rad, Haz	NFA RFI Rpt	14	TBD	Characterization	5/1/97	8/21/97
21-026(a)	Buildings/Equipment	Not Applicable	Not Applicable	Rad, Haz	NFA RFI Rpt	44	TBD	Characterization	5/1/97	8/21/97
21-026(b)	Surface/ Subsurface Material/ Waste	Not Applicable	Not Applicable	Rad, Haz	NFA RFI Rpt	44	TBD	Characterization	5/1/97	8/21/97
22-010(a)	Buildings/Equipment	Not Applicable	Not Applicable	Rad, Haz	NFA RFI Rpt	46	11.8	Report		9/29/97
22-010(b)	Buildings/Equipment	Not Applicable	Not Applicable	Rad, Haz	NFA RFI Rpt	56	27.6	Report		9/29/97
22-012	Buildings/Equipment	Not Applicable	Not Applicable	Haz, HE	NFA RFI Rpt	56	TBD	Characterization	4/1/97	9/12/97
22-014(a)	Buildings/Equipment	Not Applicable	Not Applicable	Haz, HE	NFA RFI Rpt	46	3.6	Report		9/29/97

FY 97 Schedule*

SWMU NO.	SITE TYPE	WASTE TYPE	VOLUME	POTENTIAL CONTAMINANTS	POTENTIAL REMEDIAL ACTION	SITE RANKING SCORE	AP 4.5 SCORE	WORK SCHEDULED	ANTICIPATED FIELD START	REPORT DATE
22-014(b)	Liquid Surface Impoundments	Not Applicable	Not Applicable	Haz, HE	NFA RFI Rpt	46	56.0	Report		9/29/97
22-015(a)	Surface/ Subsurface Material/ Waste	Not Applicable	Not Applicable	Haz	NFA RFI Rpt	46	34.6	Characterization	4/1/97	9/12/97
22-015(b)	Surface/ Subsurface Material/ Waste	Not Applicable	Not Applicable	Haz, HE	NFA RFI Rpt	46	8.8	Characterization	4/1/97	9/12/97
22-015(d)	Surface/ Subsurface Material/ Waste	Not Applicable	Not Applicable	Haz, HE	NFA RFI Rpt	56	32.8	Characterization	4/1/97	9/12/97
22-015(e)	Buildings/Equipment	Not Applicable	Not Applicable	Haz, HE	NFA RFI Rpt	56	17.5	Characterization	4/1/97	9/12/97
22-016	Buildings/Equipment	Not Applicable	Not Applicable	Rad, Haz	NFA RFI Rpt	56	27.6	Report		9/29/97
33-002(b)	Liquid Surface Impoundments	Not Applicable	Not Applicable	Rad, Haz	NFA RFI Rpt	51	TBD	Characterization	7/1/97	9/29/97
33-002(c)	Liquid Surface Impoundments	Not Applicable	Not Applicable	Rad, Haz	NFA RFI Rpt	51	TBD	Characterization	7/1/97	9/29/97
33-003(b)	Surface/ Subsurface Material/ Waste	Not Applicable	Not Applicable	None	NFA RFI Rpt	17	TBD	Characterization	7/1/97	9/29/97
33-004(k)	Surface/ Subsurface Material/ Waste	Not Applicable	Not Applicable	None	NFA RFI Rpt	36	14.0	Characterization	7/1/97	9/29/97
33-006(a)	Firing Ranges/Ordnance	Not Applicable	Not Applicable	None	NFA RFI Rpt	50	56.0	Characterization/ Interim Action	4/1/97	9/29/97 (IA Rpt: 4/23/97)
33-008(a)	Surface/ Subsurface Material/ Waste	Not Applicable	Not Applicable	None	NFA RFI Rpt	32	TBD	Characterization	7/1/97	9/29/97
33-008(b)	Surface/ Subsurface Material/ Waste	Not Applicable	Not Applicable	None	NFA RFI Rpt	25	TBD	Characterization	7/1/97	9/29/97
33-011(d)	Above Ground Material/ Waste	Not Applicable	Not Applicable	Rad, Haz	NFA RFI Rpt	47	56.6	Characterization	7/1/97	9/29/97
33-013	Above Ground Material/ Waste	Not Applicable	Not Applicable	Haz	NFA RFI Rpt	47	10.6	Characterization	7/1/97	9/29/97
33-017	Spills and Leaks	Not Applicable	Not Applicable	Haz	NFA RFI Rpt	46	22.3	Characterization		9/29/97
35-004(a)	Above Ground Material/ Waste	Not Applicable	Not Applicable	Haz	NFA RFI Rpt	53	3.6	Report		9/29/97
35-004(b)	Above Ground Material/ Waste	Not Applicable	Not Applicable	Haz	NFA RFI Rpt	65	22.3	Report		9/29/97
35-004(g)	Above Ground Material/ Waste	Not Applicable	Not Applicable	Haz	NFA RFI Rpt	53	3.6	Report		9/29/97
35-004(h)	Above Ground Material/ Waste	Not Applicable	Not Applicable	Haz	NFA RFI Rpt	69	50.8	Report		9/29/97
35-009(e)	Buildings/Equipment	Not Applicable	Not Applicable	Haz	NFA RFI Rpt	53	18.3	Report		9/29/97

FY 97 Schedule*

SWMU NO.	SITE TYPE	WASTE TYPE	VOLUME	POTENTIAL CONTAMINANTS	POTENTIAL REMEDIAL ACTION	SITE RANKING SCORE	AP 4.5 SCORE	WORK SCHEDULED	ANTICIPATED FIELD START	REPORT DATE
35-016(i)	Surface/ Subsurface Material/ Waste	Not Applicable	Not Applicable	None	NFA RFI Rpt	65	61.0	Report		9/29/97
36-005	Surface/ Subsurface Material/ Waste	Not Applicable	Not Applicable	Rad, Haz	NFA RFI Rpt	44	45.4	Characterization	4/1/97	9/30/97
39-001(a)	Surface/ Subsurface Material/ Waste	Not Applicable	Not Applicable	Rad, Haz, other	NFA RFI Rpt	65	TBD	Report		3/6/97
39-001(b)	Surface/ Subsurface Material/ Waste	Not Applicable	Not Applicable	Rad, Haz, other	NFA RFI Rpt	65	TBD	Report		3/6/97
39-002(a)	Above Ground Material/ Waste	Not Applicable	Not Applicable	None	NFA RFI Rpt	36	20.8	Characterization	6/1/97	9/29/97
40-005	Liquid Surface Impoundments	Not Applicable	Not Applicable	Haz, HE	NFA RFI Rpt	46	39.8	Report		9/29/97
48-007(b)	Surface/ Subsurface Material/ Waste	Not Applicable	Not Applicable	None	NFA RFI Rpt	None	49.3	Characterization	2/1/97	9/22/97
48-007(c)	Surface/ Subsurface Material/ Waste	Not Applicable	Not Applicable	None	NFA RFI Rpt	58	69.5	Characterization	4/1/97	9/22/97
48-007(f)	Surface/ Subsurface Material/ Waste	Not Applicable	Not Applicable	None	NFA RFI Rpt	58	76.5	Characterization	2/1/97	9/22/97
49-003	Liquid Surface Impoundments	Not Applicable	Not Applicable	Rad, Haz	NFA RFI Rpt	38	TBD	Characterization	6/1/97	8/25/97
49-004	Surface/ Subsurface Material/ Waste	Not Applicable	Not Applicable	Haz	NFA RFI Rpt	22	TBD	Characterization	6/1/97	8/25/97
49-005(a)	Surface/ Subsurface Material/ Waste	Not Applicable	Not Applicable	Haz	NFA RFI Rpt	22	TBD	Characterization	6/1/97	8/25/97
49-006	Liquid Surface Impoundments	Not Applicable	Not Applicable	Haz	NFA RFI Rpt	31	TBD	Characterization	6/1/97	8/25/97
53-001(a)	Above Ground Material/ Waste	PCB, PCB liquid	12cyd/ 55g	Haz	VCA	36	TBD	Remediation	9/1/97	9/30/97
73-001(b)	Surface/ Subsurface Material/ Waste	Not Applicable	Not Applicable	None	NFA RFI Rpt	32	TBD	Characterization	1/1/97	9/30/97
73-004(c)	Tanks (Septic, Above Ground)	Not Applicable	Not Applicable	None	NFA RFI Rpt	35	10.6	Interim Action/ Characterization	10/1/96	9/30/97
73-004(d)	Tanks (Septic, Above Ground)	Not Applicable	Not Applicable	None	NFA RFI Rpt	35	TBD	Characterization	1/1/97	9/30/97

FY 97 Schedule*

SWMU NO.	SITE TYPE	WASTE TYPE	VOLUME	POTENTIAL CONTAMINANTS	POTENTIAL REMEDIAL ACTION	SITE RANKING SCORE	AP 4.5 SCORE	WORK SCHEDULED	ANTICIPATED FIELD START	REPORT DATE
*Schedule Information for SWMUs with deliverables in FY98 and future years can be obtained from the Baseline.										

Attachment

Chapter 2.0 of the 1996 ER Installation Work Plan

Revision 6.1

INSTALLATION DESCRIPTION

to lie between 1.2 and 0.002 ft/yr, based on the assumption that there are no "fast paths" of water movement, such as fracture flow, to significant depths.

These calculated rates, which are relatively low, imply very little water movement from the mesa tops to the main aquifer under natural conditions, which probably also applies to a one-time spill of contaminants at the land surface. Because of geochemical interaction between the rock and dissolved constituents, the rate of constituent movement (except for movement of constituents that are highly soluble) should be lower than that of water.

The greatest concern about subsurface migration at mesa tops is the potential for a large volume of contaminants to be chronically released in the vicinity of open and interconnected joints, which could occur beneath a surface impoundment or a leaky chemical storage tank. The movement of water through joints would negate the protection provided to the groundwater when water moves only through pores in the tuff (Abrahams 1963, 8149).

Filled fractures strongly inhibit moisture movement. Open fractures are effective barriers to liquid phase unsaturated flow but may provide preferential flow paths for vapor transport or rapid movement of liquid under saturated or near-saturated conditions (Abeele et al. 1981, 6273). Roots have been found in joints to depths of at least 42 ft (Weir and Purtymun 1962, 11890), which suggests that joints may be important local infiltration pathways. Several fracture zones at TA-54 show an increase in moisture content relative to adjacent porous media (Kearl et al. 1986, 8414).

Although fractures have a local effect on infiltration in the upper portions of the mesas, it is less clear to what depth they play a role, for three key reasons. First, water passing through a fracture system has a tendency to be "wicked" into the adjacent rock matrix by capillary suction forces in the tuff, provided the fracture/rock interface is not sealed with material of low permeability (Thoma et al. 1992, 57004). Analytical and numerical modeling at TA-54 indicates that transient infiltration pulses in fractures likely affect only the very near surface before being imbibed by the adjacent tuff (Rosenberg et al. 1993, 46223). Second, most of the open fractures occur in the moderately welded to welded Tshirege Member of the Bandelier Tuff, and the underlying nonwelded Otowi Member is significantly less fractured (Baltz et al. 1963, 8402). Flow in the lower portions of the Bandelier Tuff, therefore, is far more likely to be dominated by the relatively slow process of capillarity.

Finally, although fractures may initially provide a pathway for movement of water into the mesas, they may later play a role in removing water (as water vapor) from within the mesa. Under low barometric pressure conditions, air transfers from the tuff to the atmosphere through boreholes (Purtymun et al. 1974, 5477). Barometric and air pressure variations along the canyon walls could cause the exchange of gas and water vapor between the atmosphere and the mesas, especially via interconnected fractures and joints, which are highly permeable to air. Air transfer has been documented in boreholes penetrating the tuff at TA-49 (Purtymun et al. 1974, 5477) and has been observed elsewhere on the plateau.

In conclusion, the combination of the Bandelier Tuff's low moisture content beneath the mesa tops, its associated hydraulic characteristics, and its thickness provides the main aquifer a substantial degree of protection from the mesa tops. At suspected waste sites at which contaminated liquids have not been disposed, the risks to the main aquifer are quite low. Detailed characterization of the subsurface probably is not warranted for most such sites. Site-specific conditions must always be considered, however, before making such a determination. At waste sites with large potential contaminant source terms, such as material disposal areas, phased subsurface investigations should be conducted to verify that the waste is sufficiently contained.

Waste disposal activities that chronically released large volumes of and highly contaminated liquids or that contained volatile contaminants have the potential for migration within the mesas and should also be investigated for subsurface transport. Open fractures may be a key factor in determining

gravity by surface tension forces. Thus, a slug of water entering dry tuff is slowed or retained by capillary tension forces.

Water moves through the tuff in two ways: (1) by liquid and vapor movement through the pores of the tuff and (2) by movement through open, interconnected joints (Abrahams 1963, 8149). When moisture content is low, movement in the vapor (gaseous) phase becomes more preponderant, and liquid movement through the rock matrix is extremely slow. Water entering open, interconnected joints might move rapidly downward through the joints; however, to maintain continuous flow through the fractures, it is likely that large volumes and a continuous supply of water are necessary because of the sponge effect of the adjacent tuff that forms the wall of the fracture. The existence of a low-permeability coating on the wall of the fracture, on the other hand, could increase the travel depth of water flowing through fractures (Thoma et al. 1992, 57004). If the joints are not continuous through contacts between subunits of the tuff, the water might be perched above the contact and would tend to move laterally, potentially to the walls of canyons. These factors are discussed as they pertain to subsurface contaminant transport beneath the mesa tops and canyon bottoms.

2.5.5.1 Migration of Moisture Beneath Mesa Tops

The natural moisture content of the tuff forming the mesas between the canyons is generally less than 5% by volume at depths greater than a few tens of feet, the zone affected by seasonal inputs of moisture and evapotranspiration. Weir and Purtymun (1962, 11890) attributed the low moisture content to the protective cap of clay soil derived by weathering of the tuff near the surface, low rainfall, and high evapotranspiration. The existence of low moisture content is further supported historically by the absence of weathering below 10 m (Wheeler et al. 1977, 5577) and the overall absence of perched water in the tuff at potential perching horizons.

Kearl et al. (1986, 8414) concluded that vapor phase transport is the predominant transport mechanism controlling the potential subsurface movement of contaminants beneath the mesa top at TA-54. They also conclude that there is no interconnection or movement of liquid water in the interval of Bandelier Tuff examined (upper 100 ft of the Tshirege Member). Other laboratory analyses on cores of moderately welded tuff support the possibility of vapor phase dominance at most mesa top locations (Abrahams 1963, 8149).

From a waste containment perspective, the possibility of vapor phase dominance is significant: in extremely dry rock, only contaminants existing in a gaseous state, such as tritium or volatile organic solvents, migrate through the rock matrix. Other radionuclides and metals can be removed from their original location only under wetter conditions, when the uninterrupted movement of liquid water (i.e., capillarity) is more predominant.

Few definitive field measurement techniques exist by which to quantify natural recharge through mesa tops. One exception is the use of natural tracer profiles to infer recharge rates by comparing them with analytical solute transport solutions. As an alternative, the flux of liquid water through the rock matrix that could eventually become recharge can be estimated as being approximately equal to the unsaturated hydraulic conductivity, assuming that flow is downward and at steady state.

In situ hydraulic conductivities for tuff beneath the mesa top MDA L at TA-54 were computed by Rogers and Gallaher (1995, 55334) from laboratory analyses of five undisturbed Bandelier Tuff cores obtained from three separate coreholes. Computed *in situ* unsaturated hydraulic conductivities (i.e., fluxes) range from 3.0 x 10-12 to 1.5×10^{-1} cm/sec (3.7×10^{-5} to 1.9×10^{-1} ft/yr). For uniform flow through media with spatially varying hydraulic conductivity, the average hydraulic conductivity lies between the harmonic and arithmetic mean hydraulic conductivity (de Marsily 1986, 57043). The arithmetic and harmonic mean hydraulic conductivities for this set of cores are 4.7×10^{-9} and 8.7×10^{-12} cm/sec (5.8×10^{-2} and 1.1×10^{-4} ft/yr). At the moisture conditions and calculated unsaturated hydraulic conductivities at MDA L, the rates of water movement in the upper part of the mesa top are estimated

2.5.4.4 Moisture Characteristic Curves

The relationship between moisture content and soil-water potential has been obtained from more than 60 undisturbed mesa top and canyon bottom cores at TA-54 (Rogers and Gallaher, 1995, 55334). The data indicate residual moisture content (0% to 4%). Purtymun and Stoker (1987, 6688) indicate that at TA-49 specific retention (residual moisture content) ranged from 11% to 27%. Detailed analyses in Mortandad Canyon show that there are significant differences in moisture retention characteristics between and within formational units (Stoker et al. 1991, 7530). Abrahams (1963, 8149) determined the energy relationship with moisture content of a moderately welded tuff. The saturated moisture content of the tuff was about 41% by volume. When moisture contents are below about 4%, there is no movement of water; from about 4% to 8%, moisture is redistributed by diffusion; from about 8% to 23%, distribution is governed by gravity and capillarity; and above 23%, movement is controlled by gravity only (Abrahams 1963, 8149).

2.5.4.5 Hydraulic Conductivity

Hydraulic conductivity is the parameter that describes rate of flow of fluid through a porous medium in response to a hydraulic gradient; it is a function of both the fluid and the medium. Saturated hydraulic conductivities have been measured for tuff many times under laboratory and field conditions, with values ranging from 1.9×10^{-5} to 2.3×10^{-2} cm/s (0.054 to 6.5 ft/day), comparable to those of silty sand. In general, nonwelded tuff has greater saturated conductivity than welded tuff, and horizontal conductivities are greater than vertical conductivities (Abrahams 1963, 8149). Unsaturated hydraulic conductivities may be many orders of magnitude lower, typically ranging from 10^{-6} to 10^{-11} cm/s (Stoker et al. 1991, 7530; Rogers and Gallaher 1995, 55334), depending on *in situ* moisture contents.

2.5.4.6 Joints

Joints formed by cooling of the ash flows or by later faulting typically divide the tuff into irregular blocks. The major joint sets are vertical or nearly vertical, with dips greater than 70°, and joint frequency increases with the degree of welding and proximity to faults (Vaniman and Wohletz 1990, 21589). Joints and fractures in moderately welded tuffs generally terminate in nonwelded tuffs (Baltz et al. 1963, 8402). The joints are often vertically limited to a single ash flow or ash fall unit (Purtymun and Kennedy 1971, 4798). Joint apertures range from closed to open as much as 15 cm (Wohletz 1995, 54404). The joints are commonly filled with pedogenic calcite near the surface, grading downward to clay, and may be open to depths greater than 30 ft (Purtymun et al. 1978, 5728; Abeele et al. 1981, 6273). Examination of cores obtained from horizontal drilling beneath a waste disposal site at TA-54 showed that about 80% of the joints were filled or plated with clay or secondary mineralization (Purtymun et al. 1978, 5728). Fracture apertures at TA-54 are typically small, with median values of about 3 mm; median fracture spacing is 1.9–4.0 ft (Reneau and Vaniman, in preparation, 55122). Reneau and Vaniman note the general absence of clay illuviation in any fractures to depths greater than 10–20 ft within an excavated pit at TA-54.

2.5.5 Movement of Moisture in the Bandelier Tuff

The movement of moisture in the Bandelier Tuff is governed by a complex interaction of many factors. Climatic and site-specific land use factors control the supply of moisture available for infiltration, and hydrogeological characteristics control the redistribution of moisture in the tuff.

Perhaps the most significant aspect of the tuff is its ability to imbibe water, i.e., act as a sponge. Most of the pore spaces in the tuff are of capillary size and have a strong tendency to hold water against

TABLE 2-2
SUMMARY OF HYDRAULIC PROPERTIES DATA FOR BANDELIER TUFF OBTAINED SINCE 1984

				van Genuchten Parameters		
	Bulk Density (g/cm^3)	Porosity (%)	Ksat (cm/sec)	Residual Saturation (%)[b]	α	N
Tshirege Member						
Minimum	0.94	34.6	5.6×10^{-6}	0.0	0.0011	1.152
Median	1.18	48.8	1.1×10^{-4}	2.3	0.0056	1.696
Harmonic Mean			5.8×10^{-5}			
Maximum	1.49	74.2	3.9×10^{-3}	7.9	0.2312	2.877
Number of Observations	43	63	85	32	32	32
Tsankawi Pumice						
Minimum	0.90	36.7	4.7×10^{-5}	0.0	0.0005	1.106
Median	1.25	46.0	6.8×10^{-4}	0.23	0.0187	1.481
Harmonic Mean			1.7×10^{-4}			
Maximum	1.60	65.6	4.3×10^{-3}	7.28	0.0513	1.890
Number of Observations	18	12	9	9	9	9
Otowi Member						
Minimum	0.98	40.3	1.1×10^{-5}	0.0	0.0039	1.388
Median	1.18	44.0	2.7×10^{-4}	2.5	0.0060	1.653
Harmonic Mean			1.3×10^{-4}			
Maximum	1.49	59.0	7.8×10^{-3}	12.1	0.0185	2.307
Number of Observations	31	25	25	21	21	21

---

a. Samples represent a compilation by D. Rogers and B. Gallaher (1995, 55334) of available hydraulic property determinations on undisturbed core samples taken between 1984 and 1992. Field and laboratory data from USGS work in the 1950s and 1960s and air/water injection tests conducted by Bendix Corporation in the mid-1980s (Kearl et al. 1986, 8414) are not included in the compilation because of concerns relating to the comparability of different measurement techniques.

b. Most cores with $\theta_r > 10$ are omitted because of the absence of thermocouple psychrometer measurements at high matric suctions.

measured in undisturbed cores from the Bandelier Tuff is presented in Table 2-2.

Table 2-2 includes measured values for bulk density, porosity, and saturated hydraulic conductivity. The values for residual saturation, alpha, and N are the parameters for van Genuchten's formulation of the moisture characteristic curve (van Genuchten 1980, 49927):

$$\tilde{\theta} = \frac{\theta - \theta_r}{\theta_s - \theta_r} = \frac{1}{\left[1 + |\alpha h|^N\right]^M}$$

where

$\tilde{\theta}$	effective saturation,
θ	volumetric moisture content,
θ_s	saturated moisture content,
θ_r	residual moisture content,
h	suction,
α, N	van Genuchten fitting parameters,
M	= 1-1/N.

2.5.4.1 Effects of Physical Characteristics

Physical characteristics of the tuff that affect fluid flow result primarily from the degree of welding and jointing. The degree of welding, which varies markedly within and between tuff units, influences the nature and variability of hydrologic characteristics. Welding results in increased density, decreased porosity, and decreased hydraulic conductivity of the rock matrix (Purtymun and Koopman 1965, 11839). However, welded tuffs tend to be more highly fractured (jointed) than nonwelded tuff, and the overall permeability of the welded tuff may be locally enhanced (Crowe et al. 1978, 5720).

2.5.4.2 Porosity

Porosity measurements by Abrahams (1963, 8149) range from 20% to 60% by volume, generally decreasing with increasing degree of welding. Measurements reported by IT Corporation (1987, 8998) are higher, from approximately 39% to 74%. A great deal of the high porosity occurs whenpumice fragments are incorporated in the tuff. The higher porosities are comparable to those of the upper ranges found in fine clays. Such high porosities, however, are unusual for indurated materials. Extreme changes in porosity over a short vertical distance have been observed (Abrahams 1963, 8149).

2.5.4.3 Moisture Content

A number of hydraulic properties of the Bandelier Tuff vary with changing moisture content. The tuff is only partially saturated throughout the Laboratory, even beneath stream channels containing alluvial perched groundwater systems. The moisture contents of the tuff beneath mesa tops are very low, typically less than 5% by volume (Abrahams 1963, 8149). Abrahams shows that tuff moisture content is higher beneath disturbed soils than beneath undisturbed soils and, generally, moisture content decreases with depth. At sites with relatively high near-surface moisture contents, the volumetric moisture content decreases rapidly with depth to less than 5% (Abrahams 1963, 8149). Moisture contents of the tuff beneath the canyon bottoms are considerably higher than those beneath the mesas and typically range from 20% to 50% by volume (Weir and Purtymun 1962, 11890; Stoker et al. 1991, 7530). Field studies in Mortandad, Sandia, and Potrillo Canyons show that moisture content varies greatly with depth, depending on texture (Stoker et al. 1991, 7530; Environmental Protection Group 1993, 23249). Generally, moisture content decreases with depth below stream channels.

In addition to availability of recharge from overlying alluvial groundwater, the location of intermediate perched zones is controlled by hydrogeologic characteristics of subsurface units, mainly lithology and permeability. In some cases, such as with interlayered basalts and conglomerates, intermediate perched zones could occur at several depths beneath a canyon.

The intermediate perched zones have not been observed to extend laterally beneath mesas. However, some lateral spreading of perched groundwater may occur down gradient, if the canyon course and the dip of the perched zone do not coincide.

Some hydrologic evidence suggests the existence of an intermediate perched zone within the Bandelier Tuff along the western portion of the Laboratory, but this can not be confirmed without further study.

Contaminant concentrations in water entering these intermediate perched zones are diluted. Lateral, down-canyon flow within intermediate perched zones could contribute to significant transport of contaminants away from their surface source.

2.5.3.4 Regional Aquifer

The slope of the top of the regional aquifer suggests that the flow of groundwater is generally towards the east or southeast, and towards the Rio Grande.

Intermediate perched zone and alluvial groundwater may be minor sources of recharge to the regional aquifer. The hydraulic connection between the regional aquifer and the land surface is not strong. Regional aquifer groundwater within the eastern portion of the Pajarito Plateau (generally along the Rio Grande) is of different recharge origin than under the central part of the Plateau.

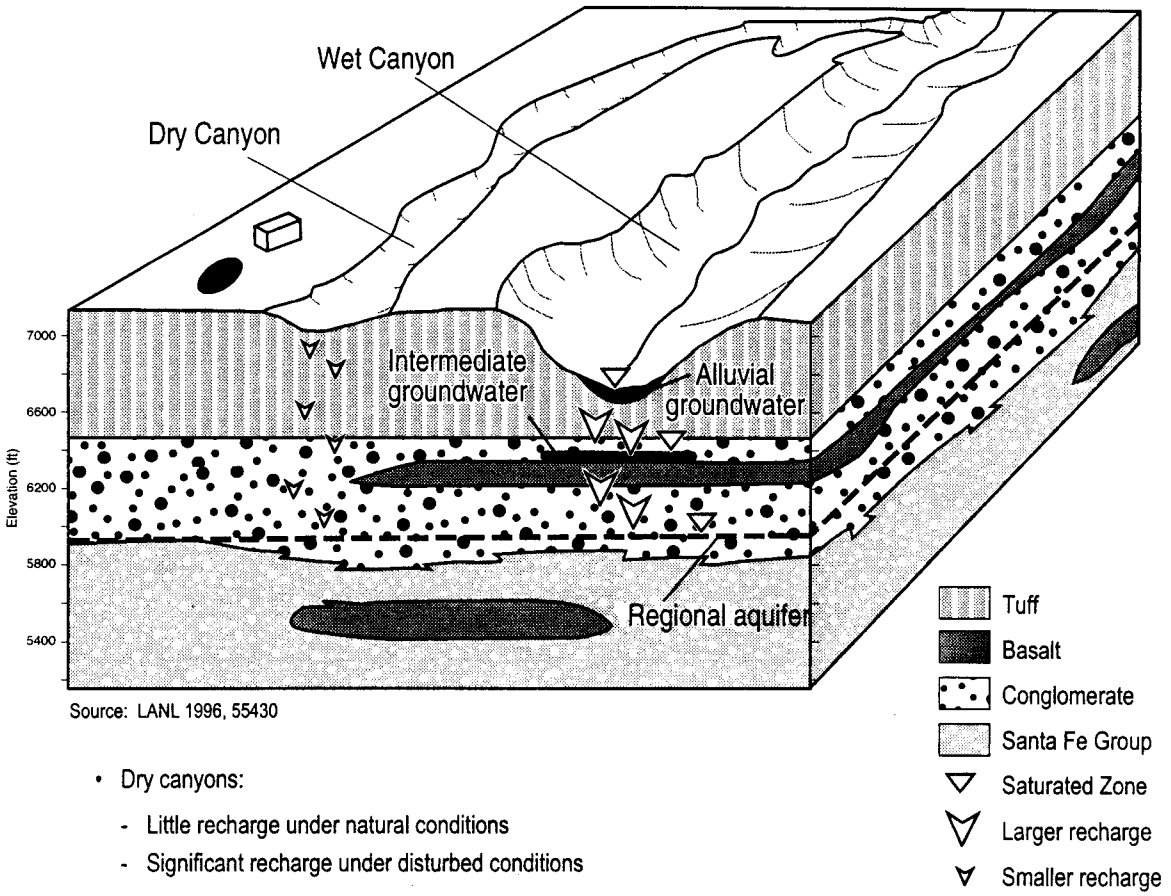
Sources of recharge to the regional aquifer are uncertain. Geochemical data show that the Valles Caldera is not the source of major recharge, contrary to statements in earlier Laboratory reports. Major recharge may occur by southerly flow along the late Miocene trough of Purtymun (1984, 6513).

If present, Laboratory-derived contaminants in the regional aquifer are likely to vary in concentration. The contaminant concentrations are probably below maximum contaminant levels (MCLs) for drinking water because; (1) regional aquifer underflow dilutes contaminant concentrations in recharge; and (2) contaminant concentrations in alluvial and intermediate perched zone groundwater are expected to decrease with depth due to dilution and geochemical attenuation along vertical migration pathways.

2.5.4 Hydrologic Properties and Conditions of the Bandelier Tuff

In the central portion of the Laboratory, there is in excess of 1,000 ft or more of unsaturated volcanic tuff, sediments, and basalts of the Bandelier Tuff, the Puye Formation, and the basaltic rocks of Cerros del Rio. Numerous investigations focusing on hydrologic characterization of the upper 100 ft of the Bandelier Tuff have been conducted in the Los Alamos area since the 1950s (e.g., Abrahams et al. 1961, 8134; Weir and Purtymun 1962, 11890; Abrahams 1963, 8149; Purtymun and Koopman 1965, 11839; Purtymun and Kennedy 1971, 4798; Purtymun et al. 1978, 5728; Abeele et al. 1981, 6273; Kearl et al. 1986, 8414; Purtymun et al. 1989, 6889; Stoker et al. 1991, 7530). The vadose zone below about 100 ft has not been adequately characterized.

Most of the investigations of the hydrogeologic properties of the Bandelier Tuff have been conducted on samples of crushed or disturbed tuff. Hydrologic property tests conducted since the mid-1980s largely have been on undisturbed cores (e.g., Kearl et al. 1986, 8414; Stoker et al. 1991, 7530). To aid the reader in evaluating the variablity in hydraulic properties, a summary of hydraulic properties



Source: LANL 1996, 55430

- Dry canyons:
  - Little recharge under natural conditions
  - Significant recharge under disturbed conditions
- Wet canyons:
  - Source of recharge to intermediate groundwater and regional aquifer
- Intermediate groundwater:
  - Significant contaminant transport path
  - Source of recharge to main aquifer
  - Occurs in larger canyon systems
  - May exist beneath canyons
  - May be laterally extensive near Jemez Mountains
  - Controlled by subsurface lithology

Figure 2-20. Hydrogeologic conceptual model for canyons.

wet canyons contain ephemeral streams and contain groundwater in the canyon bottom alluvium (Figure 2-20). A third component, intermediate perched zone groundwater, is found at depths ranging from 100 to 400 ft, and is controlled by lithology. The fourth component, the regional aquifer is found at depths of about 600 to 1200 ft (Figures 2-8, 2-15, 2-17, 2-18). Important aspects of each component of the hydrogeologic system are listed below.

2.5.3.1 Mesas

Relatively small volumes of water move beneath mesa tops under natural conditions, due to low rainfall, high evaporation, and efficient water use by vegetation. Atmospheric evaporation may extend within mesas, further inhibiting downward flow.

The amount of mesa-top recharge along the western portion of Laboratory is uncertain. Higher rainfall, increased vegetative cover, and increased welding and jointing of the tuff might lead to different recharge rates than those observed in better studied portions of the Laboratory.

Mesa-top recharge can be locally significant under disturbed surface conditions. Such change occurs when the soil is compacted, when the vegetation is disturbed, or when more water is artificially added to the hydrologic system by features such as blacktop, lagoons, or effluent disposal.

Fractures within mesas do not enhance the movement of dissolved contaminants unless saturation develops.

Contaminants in vapor form readily migrate through mesas. Vapors denser than air will sink.

2.5.3.2 Alluvial Groundwater

In drier canyon bottoms, groundwater may occur seasonally in the alluvium, depending on the volume of surface flow from snowmelt, storm runoff, and Laboratory national pollutant discharge elimination system (NPDES) -permitted effluents. As groundwater in the alluvium moves down the canyon, it is depleted by evapotranspiration and infiltration into the underlying rocks.

In wetter canyon bottoms, infiltration of NPDES-permitted effluents and natural runoff reaching the stream channel may maintain shallow groundwater in the alluvium. Groundwater levels are typically highest in late spring due to snowmelt runoff and in mid-to-late summer due to seasonal thunderstorms (Bowen 1990, 6899). Groundwater levels decline during the winter and early summer when runoff is at a minimum.

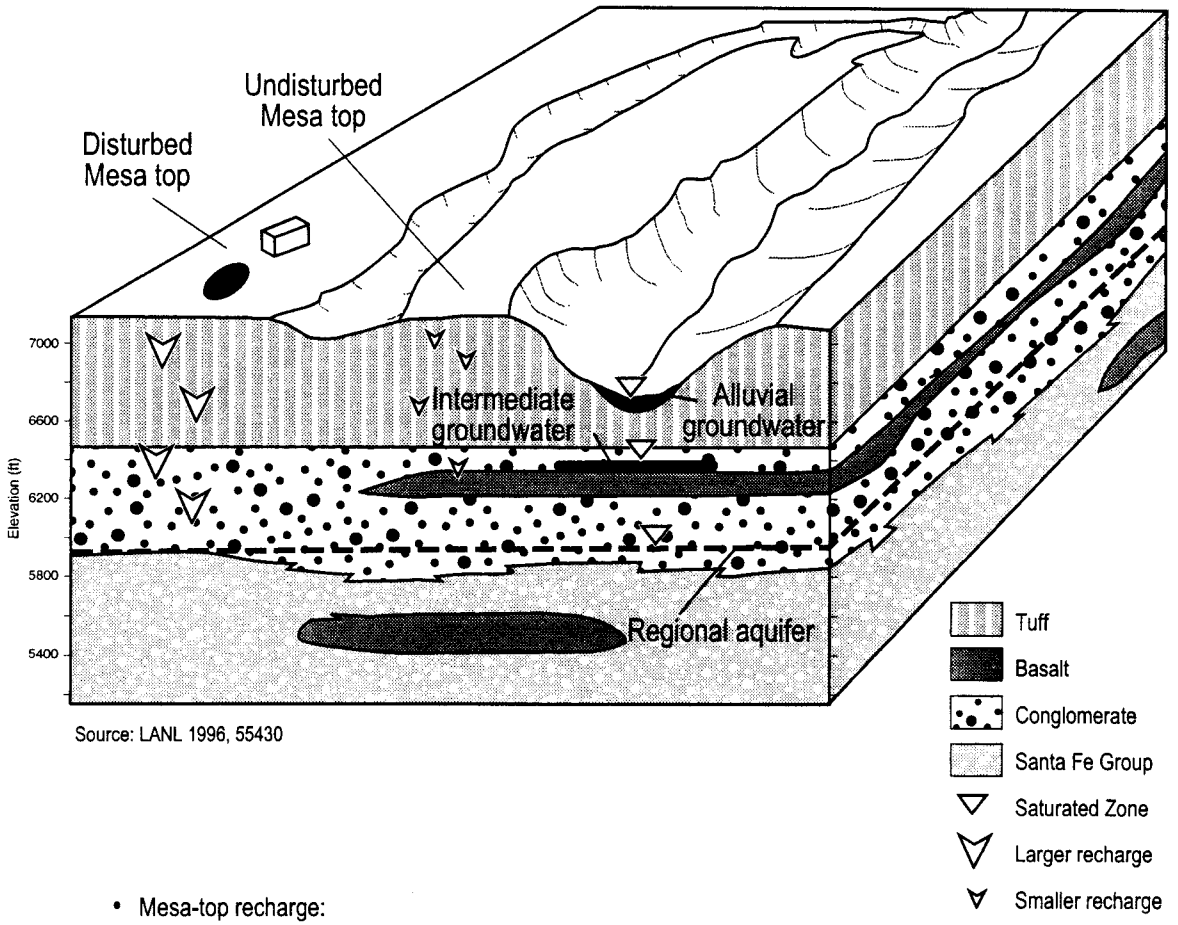
Alluvial groundwater is a source of recharge to underlying intermediate perched zones, usually by unsaturated flow.

Dry canyon bottoms contribute relatively little recharge under natural conditions. Long-term addition of effluent to naturally dry canyon bottoms may result in recharge to intermediate perched zones.

In a few cases where saturated flow might occur, faults that underlie alluvial saturated zones or intermediate perched zones could provide pathways for downward water movement.

2.5.3.3 Intermediate Perched Zone Groundwater

Intermediate perched zones occur beneath major canyon systems, particularly those that head in the Jemez Mountains. Intermediate perched zones may receive recharge from watersheds west of the Laboratory.



Source: LANL 1996, 55430

- Mesa-top recharge:
  - Small under natural conditions
  - Significant under disturbed surface
  - Fractures do not enhance unless saturated
- Air movement may dry mesa interior
- Vapor-phase contaminant movement possible

Figure 2-19. Hydrogeologic conceptual model for mesas.

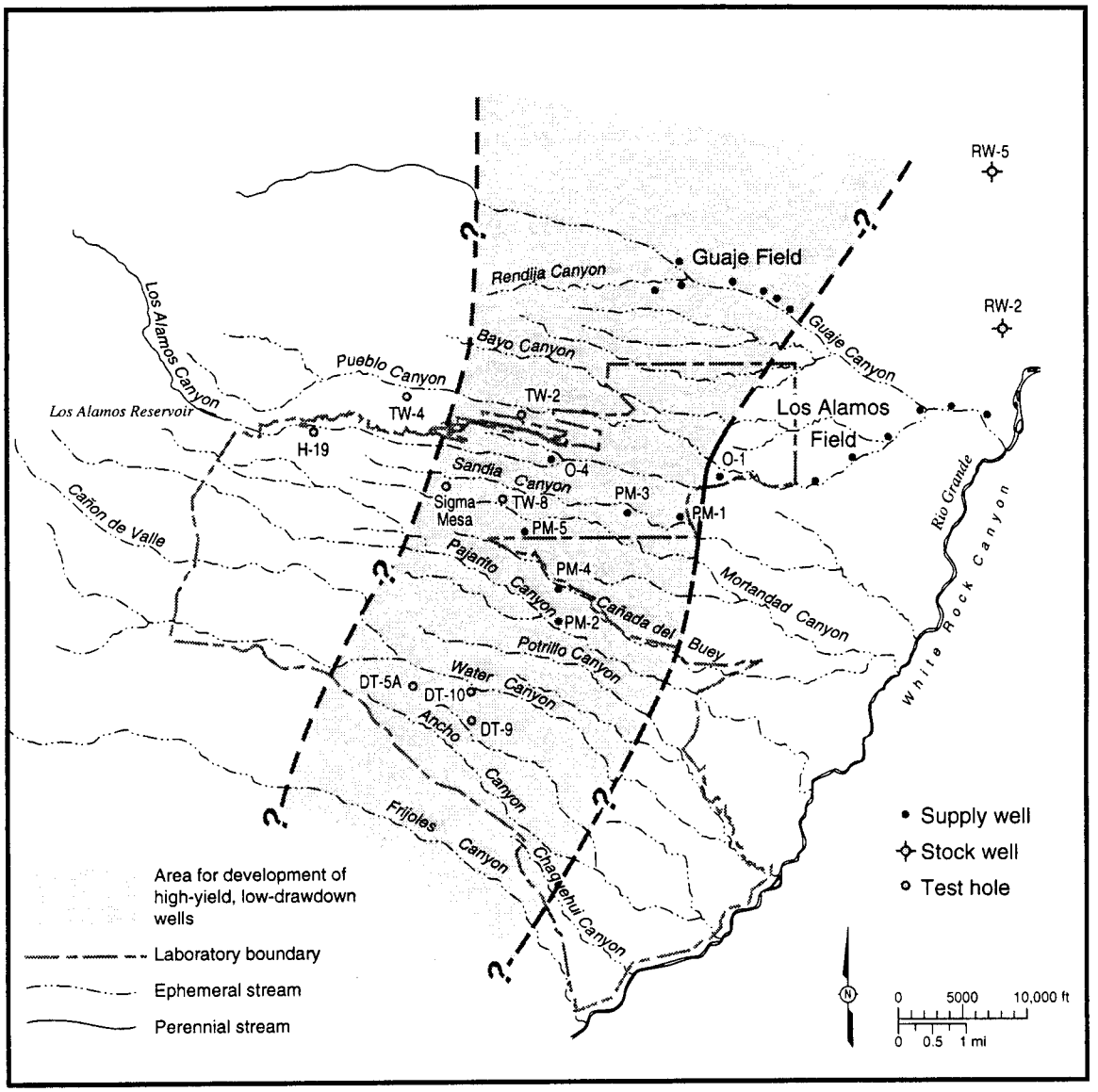


Figure 2-18. Area of inferred Late Miocene trough within upper Santa Fe Group (modified from Purtymun 1984, 6513).

In an effort to better understand the nature of recharge to the regional aquifer, additional isotope and age-dating measurements were made. Samples were collected from test wells and water supply wells that penetrate the regional aquifer. Carbon-14 and low-level tritium measurements permit some tentative estimates of the age of the water in the Regional aquifer at various locations. "Age of water" means the time elapsed since the water, as precipitation, entered the ground to form recharge and became isolated from the atmosphere. The precipitation at the time of entry into the ground is assumed to have contained atmospheric equilibrium amounts of both tritium and carbon. Radioactive carbon-14 comes mainly from natural sources. Tritium comes from both natural sources and fallout from nuclear weapons testing in the atmosphere.

The interpretation of ten carbon-14 analyses indicates that the minimum age of water in the regional aquifer ranges from about 1,000 years under the western portion of the Pajarito Plateau, increasing as it moves eastward, to about 30,000 years near the Rio Grande (Rogers et al. 1996, 54714). It is tempting to conclude that these ages support an easterly flow direction with younger water recharged at the western boundary of the plateau, and flowing towards the east. However, another possibility is that two separate groundwater bodies of different ages are represented, and that a groundwater divide in the regional aquifer lies west of the Rio Grande (Figure 2-17). The radiocarbon data consist of two geographically isolated sets of data. The older ages near the Rio Grande correspond to the region of waters with higher recharge elevations identified by Goff and Sayer (1980, 40083). The much older ages found here could reflect the longer flow path from the possible Sangre de Cristo recharge area, and support the hypothesis that the regional aquifer groundwater divide lies west of the Rio Grande. In addition, a separate flow regime may exist within the late Miocene trough of Purtymun (1984, 6513) (Figure 2-18), with major recharge occurring by southerly groundwater flow of younger water within the Rio Grande rift basin fill.

The existence of two separate groundwater masses of different ages is further supported by a discrepancy between carbon-14 ages and regional aquifer flow rates determined by Purtymun (1984, 6513). The flow rates range from about 250 ft/yr in the Puye Formation near well O-4, to about 20 ft/yr in the Tesuque Formation below the Los Alamos Well Field. For the 5.5 mi distance between wells PM-3 and LA-1B, these flow rates give a range of groundwater travel times between the wells of 115 to 1450 years. These travel times are far shorter than the 22,000 to 27,000 year difference in the carbon-14 ages for these wells (Rogers et al. 1996, 54714).

Several measurements of tritium by extremely low-detection-limit analytical methods appear to show the presence of some recent recharge (within the last 40 years) in groundwater samples taken from five locations in the regional aquifer at locations near Los Alamos (Environmental Protection Group 1994, 35363; 1995, 50276). Another thirty wells show no apparent influence of recent recharge on the regional aquifer. The tritium levels measured range from less than a percent to less than a hundredth of a percent of current drinking water standards and are less than levels that could be detected by the EPA-specified analytical methods normally used to determine compliance with drinking water regulations. The locations where tritium measurements clearly indicate the presence of recent surface recharge to the regional aquifer are (1) TW-1 situated in Pueblo Canyon near the confluence with Los Alamos Canyon; (2) TW-3, in Los Alamos Canyon; (3) in old observation and water supply wells LA-1A and LA-2, located in Los Alamos Canyon near its confluence with the Rio Grande; (4) at TW-8, in Mortandad Canyon located about a mile downstream from the outfall of the Radioactive Liquid Waste Treatment Facility (RLWTF) at TA-50; and (5) in household wells and springs at San Ildefonso Pueblo (Environmental Protection Group 1995, 50276; Blake et al. 1995, 49931).

2.5.3 Preliminary Conceptual Model for the Pajarito Plateau

For purposes of describing a conceptual model for the Laboratory, the hydrogeology of the Pajarito Plateau is broken into four components. Two of the components relate to physiography: mesas and canyons. Mesa tops are for the most part dry (Figure 2-19). Canyons are divided into wet and dry; the

Data on stable isotope (deuterium and oxygen-18) geochemistry of groundwaters from the regional aquifer and the Valles caldera indicate that most regional aquifer wells were recharged from elevations lower than the Sierra de los Valles, and do not show the trace elements characteristic of deeper Valles caldera thermal waters (F. Goff, unpublished Los Alamos National Laboratory memo 1991; Blake et al. 1995, 49931). An exception to this pattern of recharge elevations is found at former Los Alamos well field wells LA-6 and LA-1B located near the Rio Grande in lower Los Alamos Canyon (Figure 2-15). These are among the deepest of the wells in this area, and recharge elevations determined from stable isotopes suggest that the recharge area could be the Sangre de Cristo Mountains (Goff and Sayer 1980, 40083; Vuataz and Goff 1986, 40083) as suggested by flow paths in Figure 2-17.

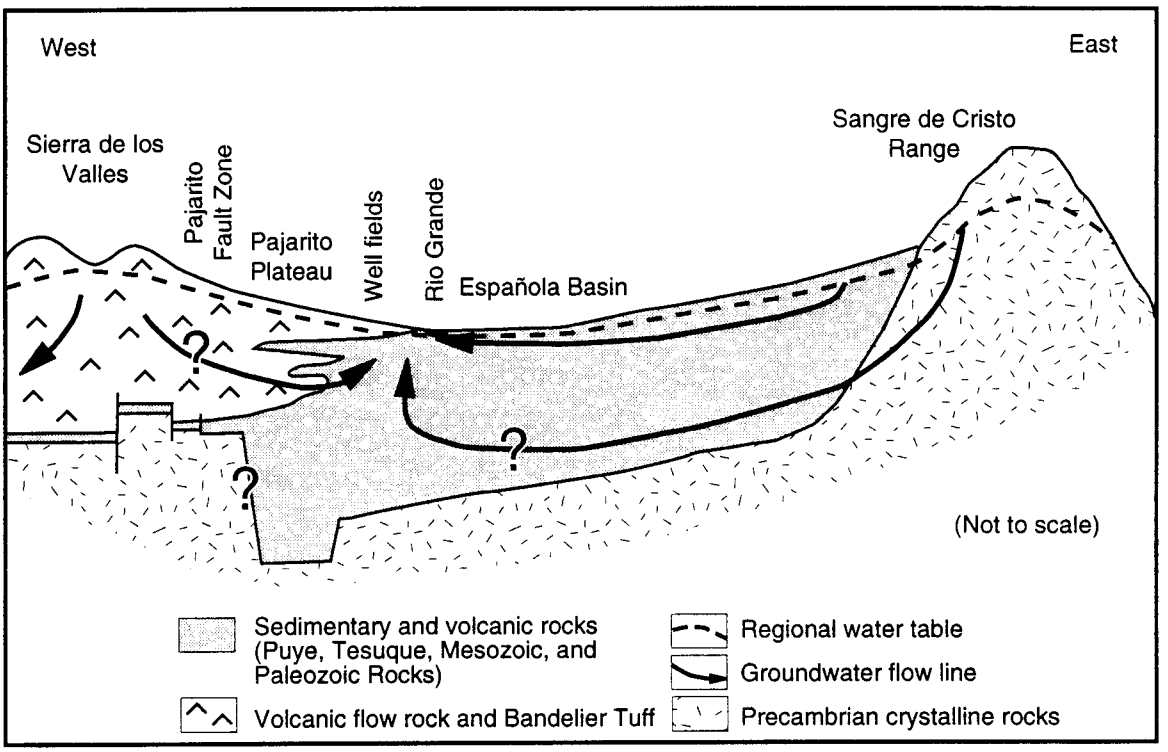


Figure 2-17. Conceptual sketch of groundwater flow paths in the Española portion of the northern Rio Grande Basin (modified from Stephens et al. 1993, 56863).

On the basis of recharge elevations estimated from stable isotope data, Blake et al. (1995, 49931) conclude that most of the regional aquifer recharge comes from the Española Basin or regions to the north along the Rio Grande, but not from the surrounding mountains. Based on stable isotope and other geochemical evidence, the Pajarito Plateau portion of the regional aquifer system appears to be recharged by a combination of lateral flow parallel to the Rio Grande Rift supplemented by inflow from the Sangre de Cristo Mountains (Goff and Sayer 1980, 40083; Vuataz and Goff 1986, 40083; Blake et al. 1995, 49931).

The above-cited studies regarding sources of recharge are inconclusive and require further investigation. The Hydrogeologic Workplan will address recharge issues as part of the characterization of the groundwater system beneath the Pajarito Plateau.

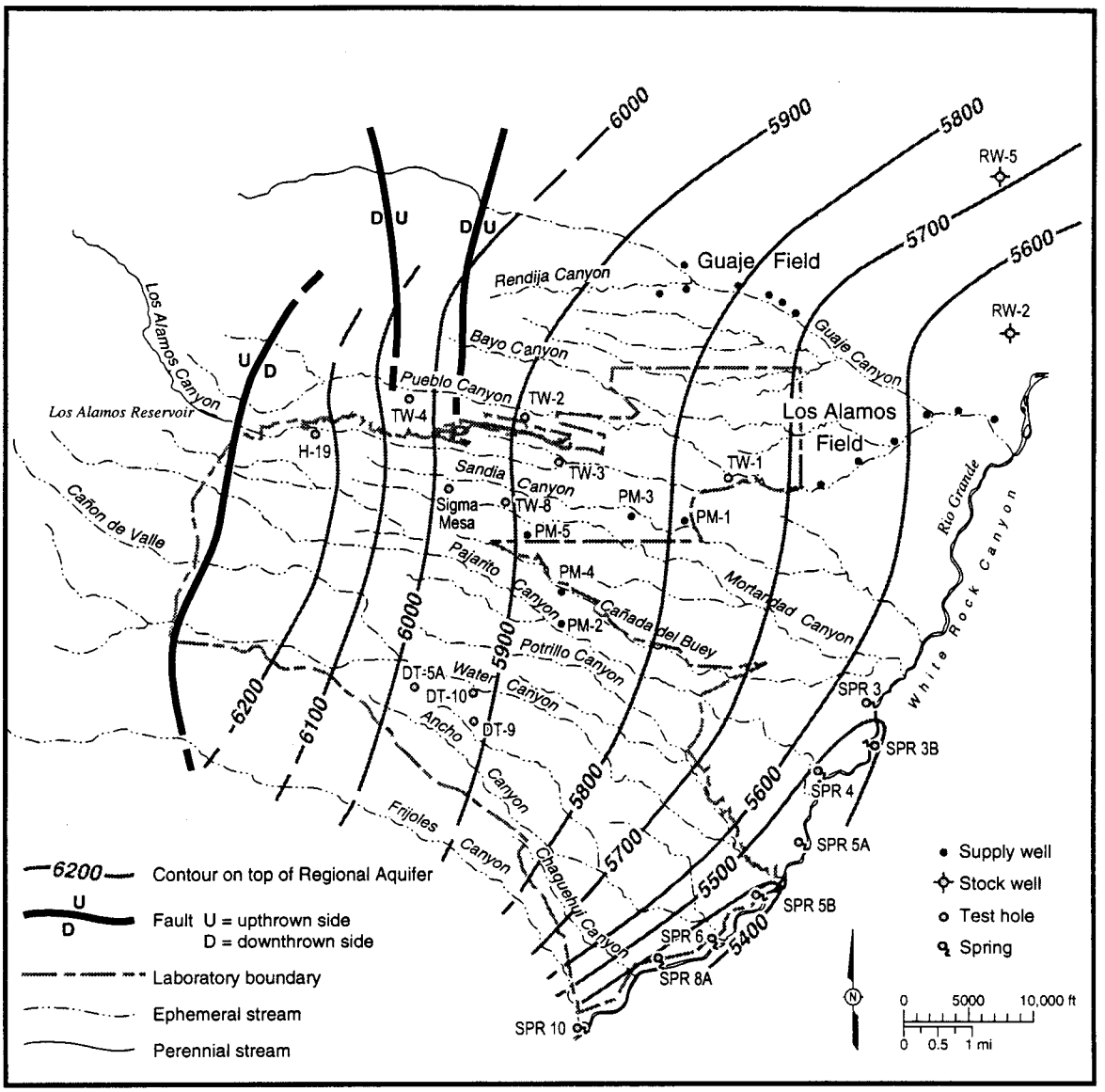


Figure 2-16. Generalized water-level contours on top of the Regional Aquifer (modified from Purtymun 1984, 6513).

(Figure 2-16). The depths to groundwater below the mesa tops range from about 1,200 ft along the western margin of the plateau to about 600 ft at the eastern margin. The regional aquifer is separated from the alluvial groundwater and intermediate perched zone groundwater by 350 to 620 ft of tuff, basalt, and sediments (Environmental Protection Group 1993, 23249). The regional aquifer exhibits artesian conditions in the eastern part along the Rio Grande (Purtymun 1984, 6513). Continuously recorded water level measurements collected in test wells since the fall of 1992 indicate that, throughout the plateau, the regional aquifer responds to barometric and earth tide effects in the manner typical of confined aquifers.

The hydraulic gradient of the regional aquifer averages about 60 to 80 ft/mi within the Puye Formation but increases to 80 to 100 ft/mi along the eastern edge of the plateau as the groundwater enters the less permeable sediments of the Santa Fe Group. The rate of movement of groundwater in the upper section of the aquifer varies depending on the materials in the aquifer. Aquifer tests indicate that the rate of movement ranges from 20 ft/yr in the Tesuque Formation to 345 ft/yr in the more permeable Puye Formation (Purtymun 1984, 6513). The highest yielding water supply wells are located within the late Miocene trough described by Purtymun (1984, 6513).

The exact source of recharge to the regional aquifer is unknown. Groundwater elevation measurements suggest that groundwater flows from the Jemez Mountains towards the Rio Grande to the east and east-southeast where a portion discharges into the river through seeps and springs (Purtymun 1984, 6513). Springs fed by the regional aquifer discharge an estimated 4,300 to 5,000 acre-ft of water annually into White Rock Canyon along an 11-mi reach between Otowi Bridge at State Road 502 and the mouth of Rito de Frijoles (Cushman 1965, 8584). Major recharge of the regional aquifer from the west is inferred because the piezometric surface slopes downward to the east (Figure 2-16). Cushman (1965, 8584) suggested three sources of recharge: infiltration of runoff in canyons; underflow from the Valles caldera through the Tschicoma Formation; and infiltration on mesas. However, a large quantity of hydrologic, structural, and geochemical data indicate that the caldera may not serve as an appreciable source of recharge to the regional aquifer (Conover et al. 1963, 57044; Griggs 1964, 8795, Goff 1991, 57039). Furthermore, natural recharge through undisturbed Bandelier Tuff on the mesa tops is believed to be insignificant (Purtymun and Kennedy 1971, 4798; Kearl et al. 1986, 8414), and few or no data exist to support an evaluation of canyon runoff as a recharge source.

To estimate recharge rates beneath the Pajarito Plateau, Rogers and Gallaher (1995, 55334) tabulated Bandelier Tuff core hydraulic properties from several boreholes beneath the Laboratory. Rogers et al. (1996, 55543) evaluated the direction and flux of water through the unsaturated zone using hydraulic properties from seven boreholes which had sufficient data. These seven boreholes represent mesa top and canyon bottom locations, which are two of the distinct hydrologic regimes on the Pajarito Plateau. Most head gradients determined for the boreholes are approximately unity, implying that flow is nearly steady state. An exception to the unit gradient was found for boreholes at Material Disposal Area (MDA) G (TA-54), where gradient reversals at depths of about 100 ft suggest that evaporative drying may be taking place. Rogers et al. (1996, 55543) used vertical head gradients and unsaturated hydraulic conductivity estimates (using geometric means) to approximate infiltration rates for liquid water at the seven sites. The flux estimates presume that flow is vertical only; that is, that no lateral flow is occurring along lithologic interfaces. Apparent fluxes beneath mesa top sites range from about 0.06 cm/yr beneath MDA G to 245 cm/yr beneath surface impoundments at TA-53. High precipitation or surface disturbances including disposal ponds lead to higher fluxes beneath some mesas. Natural tracer studies completed on three mesas across the Pajarito Plateau provide compelling evidence of a natural evaporative barrier to vertical liquid flow.

Apparent canyon bottom infiltration rates are about 0.4 to 8.3 cm/yr beneath two dry canyons (Cañada del Buey and Potrillo Canyon), and 1 to 10 cm/yr beneath Mortandad Canyon, the only relatively wet canyon represented. Canyon bottom infiltration rates beneath wetter canyons such as Los Alamos Canyon could be much greater, but no data for those sites are currently available.

system in mid-Pueblo Canyon depleted the perched groundwater after about an hour's pumping at 2 to 3 gal./min (Weir et al. 1963, 11892). Perched water was encountered in mid-Los Alamos Canyon during the drilling of the Otowi 4 supply well (Stoker et al. 1992, 12017), but it was not reported in an adjacent well (Test Well 3) located 300 ft to the east. (However, Test Well 3 was drilled with a cable tool rig in 1947, and the driller may not have noticed the perched groundwater if it was present.)

Measurements of tritium in perched groundwater at intermediate depths demonstrate that recharge to those depths has occurred during the last several decades. The levels of tritium in those locations are high enough to be attributed to recharge of surface water contaminated by effluent or other releases from Laboratory operations.

These observations have been made at four locations in Pueblo and Los Alamos Canyons. For several years, tritium has been observed in Test Well 2A in Pueblo Canyon at levels between 2,000 and 3,000 pCi/L. Starting in 1991, low-detection-limit tritium measurements have consistently revealed tritium at levels of about 150 pCi/L in samples from Test Well 1A, located in lower Pueblo Canyon near its confluence with Los Alamos Canyon, and in Basalt Spring, located in Los Alamos Canyon just downstream from its confluence with Pueblo Canyon. The measurements at these three locations are consistent with previous understanding. The intermediate perched groundwater has long been known to be affected by effluents discharged into Pueblo Canyon, starting with measurements made by the USGS in the 1950s and 1960s (Abrahams et al. 1961, 8134).

The most recent observation of tritium in intermediate-depth groundwater was made in Well LADP-3, completed in 1993 by the Environmental Restoration (ER) Project in the middle reach of Los Alamos Canyon, about 1 mi down gradient of TA-2, the Omega Reactor (Broxton et al. 1995, 50119). Well LADP-3 encountered perched water at a depth of about 320 to 330 ft, above the contact between the Otowi Member and the Puye Formation. Samples of water from that well contained about 6,000 pCi/L tritium, but concentrations had decreased to <1,000 pCi/L by 1996.

Some perched water occurs in volcanics on the flanks of the Jemez Mountains offsite to the west of the Laboratory. This water discharges in several springs (including American and Armistead Springs) and provides flow for the gallery in Water Canyon. The gallery contributed to the Los Alamos water supply for 41 years, producing 23 to 96 million gal. annually.

Several springs have been noted in the area of S-Site by the New Mexico Environment Department (NMED) DOE Oversight Bureau (unpublished data). Some of these springs are located within canyon bottom alluvium where groundwater return flow to the dry stream channel occurs and do not represent springs in the usual sense. In other cases flow issues from canyon walls well above the alluvium. The origin of water supplying these springs is uncertain at present. In some cases the flow may have its source from nearby outfalls. The ER Project and NMED DOE Oversight Bureau (unpublished data) have discovered high-explosives residuals in samples from some of these springs.

2.5.2.3 Regional Aquifer

The regional aquifer of the Los Alamos area is the only aquifer capable of large-scale municipal water supply (Purtymun 1984, 6513). In 1989, water for the Laboratory, the communities of Los Alamos and White Rock, and Bandelier National Monument was supplied from 11 deep wells in 3 well fields. The wells are located on the Pajarito Plateau and in Los Alamos and Guaje Canyons east of the plateau. Municipal and industrial water supply pumpage during 1992 was 1.43 billion gal. Yields from individual wells ranged from about 175 to 1,400 gpm (Stoker et al. 1992, 12017). Purtymun (1984, 6513) summarized the hydraulic characteristics of the aquifer as determined during aquifer tests and during periods of production of supply wells and test holes.

The surface of the regional aquifer rises westward from the Rio Grande within the Santa Fe Group into the lower part of the Puye Formation beneath the central and western part of the Pajarito Plateau

to the community and the Laboratory. Lateral flow of the alluvial perched groundwaters is in an easterly, downcanyon direction. Tracer studies in Mortandad Canyon have shown that the velocity of water ranges from about 60 ft/day in the upper reach to about 7 ft/day in the lower reach of the canyon (Purtymun 1974, 5476).

The water quality in the alluvial perched groundwaters is variable, depending on the location and history of effluent discharges. In Mortandad Canyon, for example, plutonium concentrations fluctuate up and down in response to variations in treatment plant effluent and storm runoff water, which cause some dilution of the shallow alluvial perched groundwater. Tritium concentrations have fluctuated almost in direct response to the average annual concentration of tritium in the TA-50 effluent, with a lag time of about 1 year (Environmental Protection Group 1992, 7004).

Purtymun (1975, 11787; 1973, 4971) has written reviews of alluvial perched groundwaters by drainage area. The results of an extensive monitoring study of the alluvial perched groundwater in Mortandad Canyon are presented by Abrahams et al. (1962, 8140), Baltz et al. (1963, 8402), Purtymun (1973, 4971), Purtymun (1974, 5476), Purtymun et al. (1977, 11846), Purtymun et al. (1983, 6407), and Stoker et al. (1991, 7530).

2.5.2.2 Intermediate Perched Groundwater

Localized bodies of perched groundwater occur beneath several canyons in the eastern portion of the Laboratory, along the eastern flanks of the Jemez Mountains west of the Laboratory, and beneath the mesas and canyons at S-Site (TA-16), located in the southwestern part of the Laboratory near the Jemez Mountains. Perched groundwater may exist beneath other canyons in the south and central portions of the Laboratory, which have not yet been investigated by drilling. These perched groundwater bodies are found in areas where a sufficient water source is present to maintain saturation within the deeper units. Thus perched groundwater beneath canyon bottoms may be maintained by infiltration from the overlying stream, and perched groundwater within the Bandelier Tuff along the Jemez Mountains may be maintained by seepage from streams exiting the mountains. The presence of these perched groundwater bodies is controlled by the occurrence of a perching layer, whose lower permeability causes water to pond in a more permeable horizon above it. Perching layers are found within the interlayered Cerros del Rio Basalt flows and the sediments of the Puye Formation, for example, where they underlie the more permeable Guaje Pumice Bed in Los Alamos Canyon. The presence of perched water at S Site and on the flanks of the Jemez Mountains is evidently controlled by contrasts in lithologic properties within the Bandelier Tuff, which might exist at boundaries between flow units.

Perched water bodies occur in the conglomerates and basalts beneath the alluvium in the mid- and lower reaches of Pueblo and Los Alamos canyons and in the lower reach of Sandia Canyon. Depth to perched water ranges from about 90 ft in the midreach of Pueblo Canyon to about 450 ft in lower Sandia Canyon. The vertical and lateral extent of the perched groundwaters, the nature and extent of perching units, and the potential for migration of perched water to the main aquifer is not yet fully understood.

Patterns of chemical quality and water level measurements indicate that the intermediate perched groundwater in Pueblo Canyon is hydrologically connected to the stream in Pueblo Canyon (Abrahams and Purtymun 1966, 8141). Water from this perched groundwater discharges below the base of the basalt at Basalt Spring, which is located in lower Los Alamos Canyon on San Ildefonso Pueblo land. The rate of movement of the perched groundwater in this vicinity has been estimated at about 60 ft/day or about 6 mo from recharge to discharge (Purtymun 1975, 11787).

It is unknown whether the intermediate perched water systems are hydraulically interconnected. Available data, however, suggest that most of the systems are of limited extent: testing of the perched

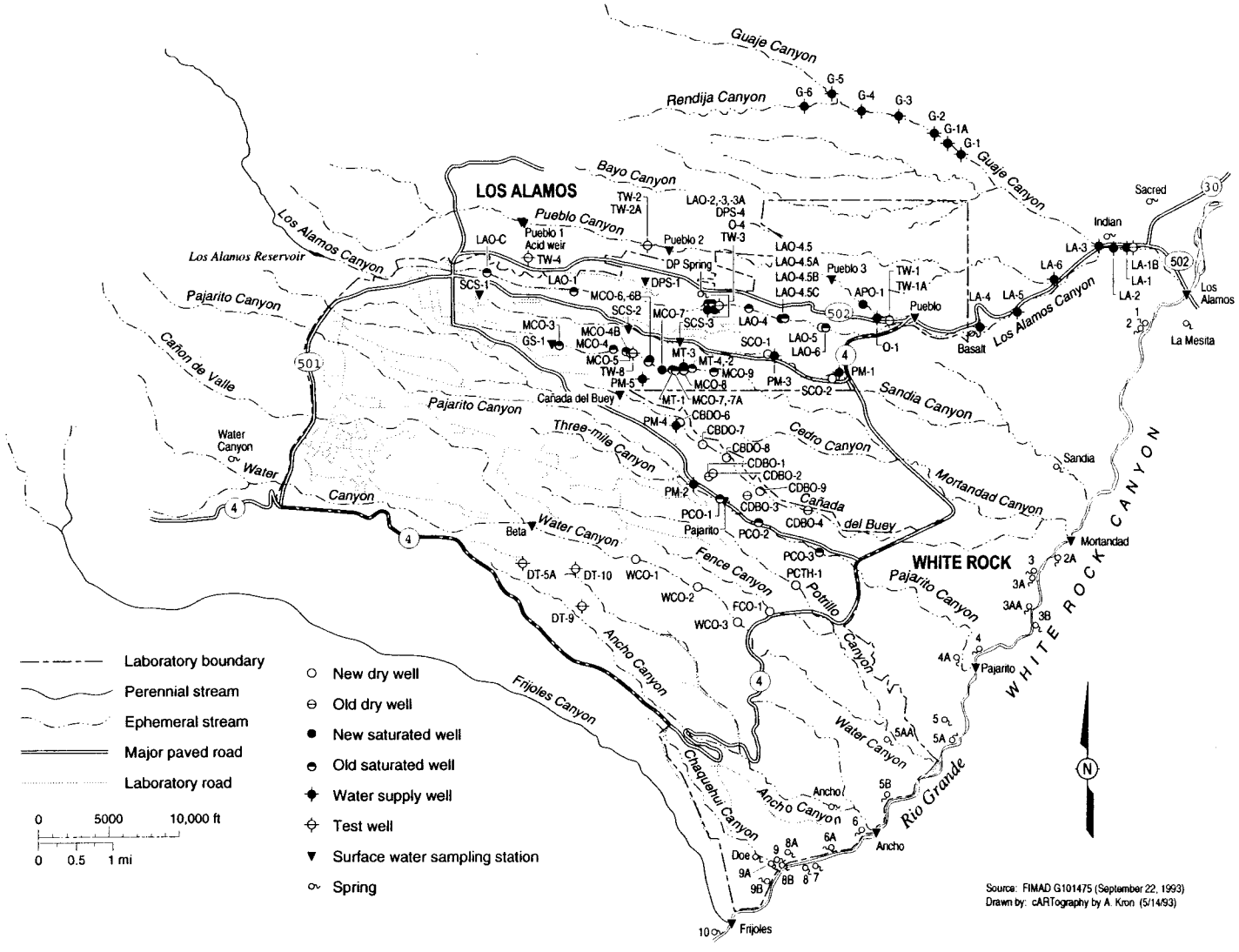


Figure 2-15. Well locations in Los Alamos County and in adjacent locales.

In canyons that have received treated, low-level radioactive effluents (Acid-Pueblo, DP-Los Alamos, and Mortandad Canyons) concentrations of radioactivity in the alluvium are generally highest near the treated effluent outfall and decrease downstream in the canyon as the sediments and radionuclides are transported and dispersed by other treated industrial effluents, sanitary effluents, and surface runoff.

A regional plutonium analysis for the Rio Grande upstream of Elephant Butte Reservoir shows that fallout contributes about 90% of the total plutonium moving through the drainage system in any given year (Graf 1993, 23251). The remaining 10% is from releases at Los Alamos. The contribution to the plutonium budget from Los Alamos is associated with relatively coarse sediment, which often behaves as bedload in the Rio Grande (Graf 1993, 23251).

A study of transport of plutonium by snowmelt runoff published in 1990 (Purtymun et al. 1990, 6992) includes the finding that most plutonium moved by runoff in Los Alamos and Pueblo Canyons that reached the Rio Grande is transported with sediments—about 57% with suspended sediments and 40% with bed sediments. A total of about 600 µCi of plutonium was carried to the Rio Grande by 5 snowmelt runoff events studied during the years 1975 to 1986.

Environmental monitoring for chemical and radiochemical quality in surface water began with USGS investigations (Purtymun 1964, 11822; 1975, 11787; Purtymun and Kunkler 1967, 11782; Purtymun 1967, 8987) and has been continued by the Laboratory (ESG until 1971; Environmental Protection Group 1994, 35363).

2.5.2 General Groundwater Conditions

Groundwater occurs in three modes in the Los Alamos Area: (1) water in shallow alluvium in some of the larger canyons, (2) intermediate perched groundwater (a perched groundwater body lies above a less permeable layer and is separated from the underlying aquifer by an unsaturated zone), and (3) the main aquifer of the Los Alamos area.

Numerous wells have been installed over the past several decades at the Laboratory and in the surrounding area to investigate the presence of groundwater in these three zones and to monitor groundwater quality. The locations of existing wells are shown in Figure 2-15.

2.5.2.1 Perched Groundwater in Alluvium

Intermittent and ephemeral streamflows in the canyons of the Pajarito Plateau have deposited alluvium that ranges in thickness to as much as 100 ft. The alluvium in canyons that head on the Jemez Mountains is generally composed of sands, gravels, pebbles, cobbles, and boulders derived from the Tschicoma Formation and Bandelier Tuff on the flank of the mountains. The alluvium in canyons that head on the plateau is comparatively more finely grained, consisting of clays, silts, sands, and gravels derived from the Bandelier Tuff. Saturated hydraulic conductivity of the alluvium typically ranges from 10^{-2} cm/s for a sand to 10^{-4} cm/s for a silty sand (Abeele et al. 1981, 6273).

In contrast to the underlying volcanic tuff and sediments, the alluvium is quite permeable. Ephemeral runoff in some canyons infiltrates the alluvium until downward movement is impeded by the less permeable tuff and sediments, which results in a buildup of a shallow alluvial groundwater body. Depletion by evapotranspiration and movement into the underlying rocks limit the horizontal and vertical extent of the alluvial water (Purtymun et al. 1977, 11846). The limited saturated thickness and extent of the alluvial groundwater preclude its use as a viable source of municipal and industrial supply

Springs on DOE property near the western Laboratory boundary occur in Pajarito Canyon and Cañon de Valle. Perennial flow has been noted associated with Homestead Spring in Pajarito Canyon. The length of the reach extends for several hundred yards (Stoker 1993, 56021). Additional springs have been located within the Laboratory boundary by Dale et al. (1996, 57014) and others. Further investigation and flow documentation is needed to validate their location and periodicity of flow.

Springs near the Rio Grande in Sandia, Pajarito, Water, Ancho, and Chaquehui Canyons are considered discharge points of the regional aquifer because of similar water chemistry. Flow from these springs maintains natural perennial reaches of varying lengths. Three of these reaches, in Water, Ancho and Chaquehui Canyons, are within the eastern Laboratory boundary. Flows from Ancho Spring in Ancho Canyon and Pajarito Spring (also known as Spring 4A) in Pajarito Canyon are known to reach the Rio Grande. Flow from Spring 9A in Chaquehui Canyon extends to a point where it meets perennial flow from Spring 9. Combined flow from Springs 9 and 9A reaches the Rio Grande (Stoker 1993, 56021). Flow from Sandia Spring in Sandia Canyon extends about 300 ft and does not reach the Rio Grande. Flow from Spring 5AA in Water Canyon is very short and does not reach the Rio Grande.

In addition to these limited natural perennial reaches, three effluent-supported reaches also exist within the watershed. Laboratory and Los Alamos County effluent discharges provide surface water flow to Pueblo and Sandia Canyons, and Cañada del Buey. The Los Alamos County Sewage Treatment Plant discharges effluent into Pueblo canyon. Effluent-supported flow reaches Los Alamos Canyon and is sampled at State Road 4 as part of the environmental surveillance program. By 1993, flow extended to the Rio Grande (Stoker 1993, 56021). Effluent discharged into Cañada del Buey 2 mi up from the confluence with Mortandad Canyon from the Los Alamos County-operated sanitary wastewater treatment plant in White Rock regularly extends to the Rio Grande (Stoker 1993, 56021). Effluent-supported flow in Sandia Canyon results from the discharge of Laboratory-treated sanitary sewage. Flow typically extends 2.5 to 3 mi (Stoker 1993, 56021).

Eleven drainage areas, with a total area of 82 mi^2, pass through the Laboratory's eastern boundary. Runoff from heavy thunderstorms and heavy snowmelt reaches the Rio Grande several times a year in some drainages. Los Alamos, Pajarito, and Water Canyons have drainage areas at the east boundary of greater than 10 mi^2. Pueblo Canyon has approximately 8 mi^2; the rest (Barrancas [a tributary to Guaje Canyon], Bayo, Sandia, Mortandad, Cañada del Buey, Ancho, and Chaquehui Canyons) have less than 6 mi^2 each. Theoretical maximum flood peaks range from 24 cfs for a 2-yr frequency to 686 cfs for a 50-yr frequency (McLin 1992, 12014). The overall flooding risk to community and Laboratory buildings is low because nearly all the structures are located on the mesa tops, from which runoff drains rapidly into the adjacent canyons.

Contaminants enter the surface water drainages by surface runoff, by liquid discharges, and occasionally by air deposition (Becker et al. 1985, 6610; Becker 1986, 6626). Runoff-derived contaminants are largely bound to sediments; their rate of downstream travel is governed by the scouring and carrying power of subsequent runoff events (Lane et al. 1985, 6604). Given sufficient time, these sediments eventually will be moved across the Laboratory boundary.

Several drainages have received liquid industrial or sanitary effluents discharged from the Laboratory. The effluent discharges determine the flow and water quality characteristics in drainages that contain little natural water. With travel downstream, most of the effluent-derived metals and radionuclides become sediment-bound and remain near the surface of the stream channel; other contaminants, such as organic solvents and/or tritium, are lost by evaporation or move downward into the alluvium. Detailed field investigations in Mortandad Canyon, for example, demonstrate that generally more than 99% of the total inventory of transuranic radioactivity discharged from the treatment plant effluents is associated with sediments in or immediately adjacent to the stream channel (Stoker et al. 1991, 7530).

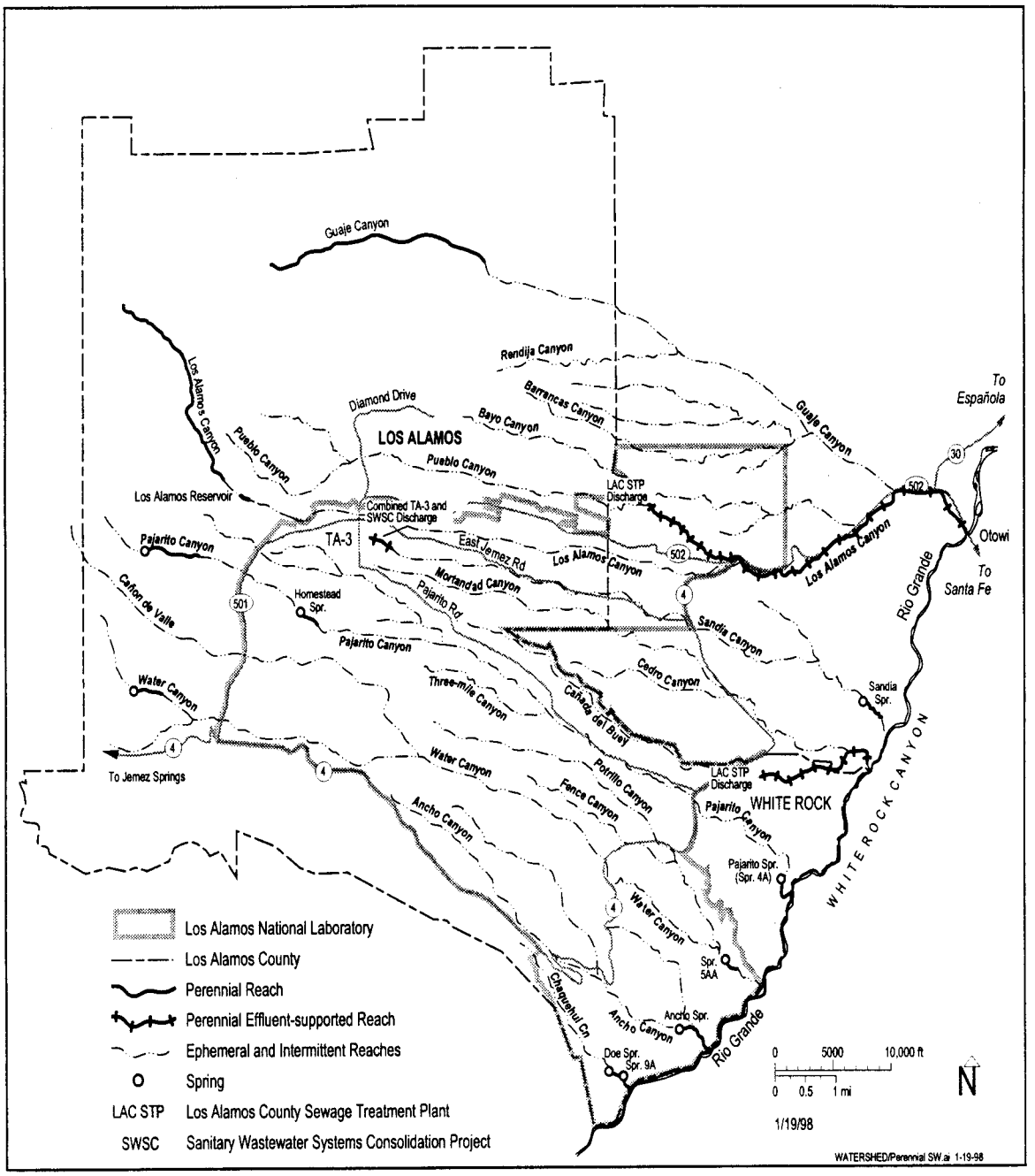


Figure 2-14. Surface water occurrences at Los Alamos (perennial and effluent-supported reaches from Stoker 1993, 56021).

In DP Canyon, a tributary to Los Alamos Canyon on the north side of TA-21, up to 6 ft (1.8 m) of sediment has been locally deposited since 1943. These young sediments in DP Canyon have been partially excavated by renewed channel incision (Reneau 1995, 50143), a process also observed in other canyons. In many canyons on the Pajarito Plateau the burial of the base of young trees indicates that a foot or more of historic (post-1942) sediment deposition on floodplains or low terraces (banks) is common. Erosion of sedimentary deposits and associated contaminants is probably caused by both vertical scouring and lateral cutting of streams during large floods. Plateau-wide summaries and syntheses of canyon-floor alluvial history are presented in Reneau and McDonald (1996, 55538) and Reneau et al. (1996, 55539).

Mass wasting processes are potentially important because they can move large volumes of material from the canyon walls to the canyon floors (e.g. Reneau, 1995, 50143; Reneau et al. 1995, 54405; and Reneau and MacDonald, 1996, 55538). In part, they create a geologic hazard in the canyon floors. For example, records for the last four decades indicate that fences in Los Alamos Canyon at TA-2 have been impacted by one boulder weighing 300 pounds or more every two years on average (McLin 1993, 50127). Burial of alluvium by rockfall debris would tend to reduce the ability of the streams to erode and transport the sediment and locally increase the residence times of contaminated sediment in the canyon floors.

2.5 Hydrology

2.5.1 General Surface Water Conditions

The Rio Grande is the primary river in north-central New Mexico. All surface water drainage and groundwater discharge from the plateau ultimately arrives at the Rio Grande. The Rio Grande at Otowi, just east of Los Alamos, has a drainage area of 14,300 mi^2 in southern Colorado and northern New Mexico. The discharge for the period of record has ranged from a minimum of 60 cubic feet per second (cfs) in 1902 to 24,400 cfs in 1920. The river transports about 1 million tons of suspended sediments past Otowi annually (Graf 1993, 23251).

Essentially all Rio Grande flow downstream of the Laboratory passes through Cochiti Reservoir, which began filling in 1976. It is designed to provide flood control, sediment retention, recreation, and fishery development. Flood flows are temporarily stored and released at safe rates. The dam is expected to trap at least 90% of the sediments carried by the Rio Grande (Graf 1993, 23251).

Most Los Alamos surface water occurs as ephemeral, intermittent, or interrupted (alternation of perennial, ephemeral, and intermittent stretches) streams in canyons cut into the Pajarito Plateau. (Ephemeral streams flow in response to precipitation; intermittent streams flow in response to the availability of snowmelt or groundwater discharge; perennial streams flow at all times except during extreme drought.) Springs on the flanks of the Jemez Mountains, west of the Laboratory's western boundary, supply flow to the upper reaches of Cañon de Valle and in Guaje, Los Alamos, Pajarito, and Water Canyons (Purtymun 1975, 11787; Stoker 1993, 56021). These springs discharge water perched in the Bandelier Tuff and Tschicoma Formation at rates from 2 to 135 gal./min (Abeele et al. 1981, 6273). The volume of flow from the springs maintains natural perennial reaches of varying lengths in each of the canyons. Figure 2-14 shows the locations of perennial reaches in the Los Alamos area.

Perennial flow in Guaje Canyon is north of the Laboratory boundary. The perennial reach extends from springs upstream of Guaje reservoir to some distance downstream of the reservoir. The perennial reach in Los Alamos Canyon is above the Los Alamos reservoir and extends to within a few hundred yards of the reservoir. Springs in the upper reaches of Pajarito Canyon support flow in a perennial reach followed by an intermittent reach to within about 0.5 mi of the Laboratory's western boundary. Flow in Water Canyon and Cañon de Valle does not reach the western boundary (Stoker 1993, 56021) (see Figure 2-14).

significant hiatus up through about 50,000 years ago (Gardner et al. 1986, 21527; Toyoda et al. 1995, 57001; Reneau et al 1996, 57002). Reports of questionable reliability describe what were apparently phreatic explosions and possible associated earthquakes within the volcanic field around 100 years ago (Santa Fe *Daily New Mexican* 1882, 57005). Regardless, given the long history of spatially focused, geologically continuous volcanic activity, future volcanism can be expected. Although volcanic activity directly affecting the Laboratory may prove unlikely, sufficient data to quantify the probabilities and nature of future volcanism are lacking.

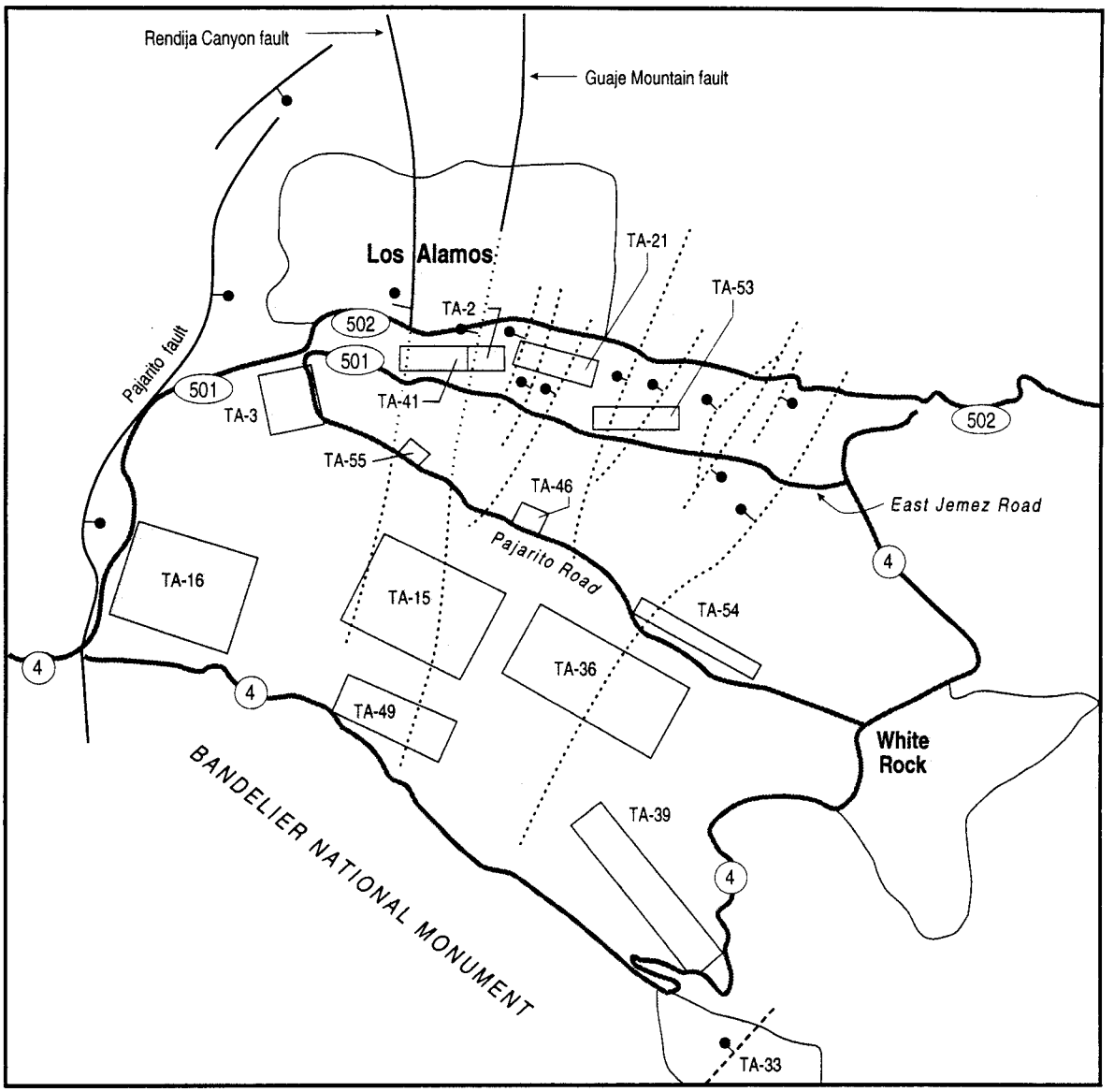
Direct effects of future seismicity at the Laboratory are likely, although quantification of probabilities is not possible at present. Numerous small earthquakes are recorded in the Los Alamos area and northern New Mexico each year (Sanford et al. 1979, 11858; Cash and Wolff 1984, 57041; Gardner and House 1987, 6682). Since establishment of the Laboratory, several earthquakes of Richter magnitude 3 to 4 have shaken Los Alamos (Gardner and House 1987, 6682). Recent work has shown that three fault segments in Los Alamos County are seismically active and that they are capable of generating large earthquakes of about 7 or more on the Richter scale (Gardner and House 1987, 6682; House and Cash 1988, 6878; Gardner et al. 1990, 48813; Gardner and House 1994, 57006). Unknown at this time are how frequently these large earthquakes occur and what their potential is for generating surface rupture and mass wasting (occurrences such as rockfalls and landslides, which are not caused primarily by the movement of water) within the confines of the Laboratory.

2.4.6 Geomorphic Processes

Significant geomorphic processes active on the Pajarito Plateau include (1) erosion of mesa top soils by runoff, (2) retreat of canyon walls by rockfall and landsliding, (3) colluvial transport on sloping portions of canyon walls, and (4) erosion and deposition of sediments by streams in the canyon bottoms. Few data exist on the rates of erosion and landscape change caused by these different processes on the Pajarito Plateau. Estimates of long-term vertical erosion rates on mesa tops have been made based on stripping of overlying units (Purtymun and Kennedy 1971, 4798), but these estimates may be of limited value because the resistant, cliff-forming units may be eroded primarily by lateral cliff retreat rather than by vertical erosion. Erosion rates vary considerably on the mesa tops; the highest rates occur in and near drainage channels and in areas of locally steeper slope gradient, and the lowest rates occur on relatively gently sloping portions of the mesa tops removed from channels. Areas where runoff is concentrated by roads and other development are especially prone to accelerated erosion.

The rates and processes of erosion may differ significantly between the north and south slopes of canyons. Given current vegetation and climate, the more extensive exposures of bedrock on south-facing sides and greater soil cover on north-facing sides suggest that erosion rates of fine-grained material that can be transported by runoff are higher on the drier, less-vegetated, south-facing sides of canyons, although this material is largely retained on the north-facing slopes. No studies have been conducted to quantify the rates and processes of erosion on canyon sides. However, the Laboratory is systematically evaluating the erosion potential in areas associated with potential release sites in order to identify the need for and prioritize stabilization efforts to minimize or eliminate potential contaminant transport.

The recent alluvial history of the canyons on the Pajarito Plateau is complex—some sediments within the stream channels are mobilized during every flood and others adjacent to or deeper beneath the channels are progressively buried and remain stable for long periods (Reneau and McDonald 1996, 55538; Reneau et al. 1996, 55539). For example, a 13-ft-deep (4.0-m-deep) trench excavated in Cabra Canyon, a tributary to Rendija Canyon immediately north of the Los Alamos townsite, revealed cycles of alternating sediment deposition and channel incision over the last 6,000 years (Gardner et al. 1990, 48813). In Cabra Canyon there has been a net accumulation of sediment over this period, although sediment deposition was interrupted by at least three episodes when channels were incised at least 3 to 6 ft (0.9 to 1.8 m), and the previously stored sediments were transported downstream.



Sources: Dransfield and Gardner 1985, 6612; Gardner and House 1987, 6682

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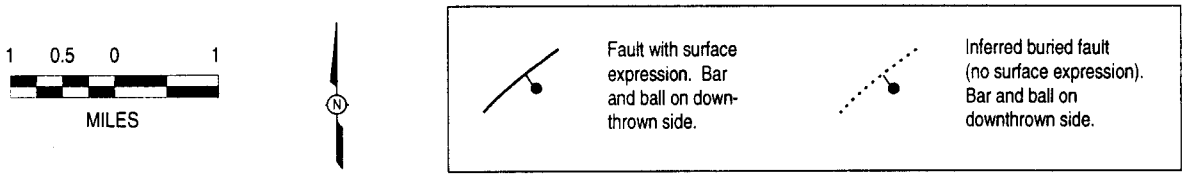


Figure 2-13. Locations of known and inferred faults at the Laboratory and in the surrounding area.

mineral components of the soils are in large part derived from the Bandelier Tuff, but dacitic lavas of the Tschicoma Formation, basalts of the Cerros del Rio volcanic field, and sedimentary rocks of the Puye Formation are locally important, and additional material may be transported to the canyons from the mesa tops by wind. Alluvium derived from the Pajarito Plateau and from the east side of the Jemez Mountains contributes to soils in the canyons and also to those on some of the mesa tops.

The soils on the slopes between the mesa tops and canyon floors have been mapped as mostly steep rock outcrops consisting of approximately 90% bedrock outcrop and patches of shallow, undeveloped colluvial soils. South-facing canyon walls are steep and usually have little or no soil material or vegetation; in contrast, the north-facing walls generally have areas of very shallow, dark-colored soils and are more heavily vegetated. The canyon floors generally contain poorly developed, deep, well-drained soils (Nyhan et al. 1978, 5702).

2.4.4 Geological Structure

The Pajarito Plateau is on the western margin of the Española basin of the Rio Grande rift, a tectonically active region. The Pajarito fault system, the major border fault on the west side of the basin, delineates the boundary between the eastern Sierra de Los Valles and the western part of the plateau. This fault system has experienced Holocene movement and historic seismicity (Gardner and House 1987, 6682; Gardner et al. 1990, 48813). Characterized by northerly trending normal faults that intertwine along their traces, the Pajarito fault system shows dominantly down-to-the-east movement and produces a series of prominent fault scarps west of the Laboratory (Figure 2-13). The vertical throw on this fault system is over several hundred feet south and west of the Laboratory but decreases northward of Los Alamos Canyon where the fault system is less prominent.

In addition to the main traces of the Pajarito fault system, other faults cut the Pajarito Plateau. The Rendija Canyon fault is a normal fault trending north-south in the west-central part of the plateau; it crosses Pueblo Canyon near its confluence with Acid Canyon and Los Alamos Canyon near TA-41 but does not have clear surface expression south of Sandia Canyon. The Guaje Mountain fault parallels the Rendija Canyon fault and is projected to cross Los Alamos Canyon near TA-2 although there is no clear offset of the Tshirege Member south of North Mesa. North of the Laboratory both of these faults have down-to-the-west movement and zones of gouge and breccia up to several meters wide, and produce visible offset of stratigraphic horizons and recognizable scarps. However, these features are not apparent within most of the Laboratory. Vaniman and Wohletz (1990, 21589) and Wohletz (1995, 54404) project these faults south of Los Alamos Canyon, based on Tshirege Member rock fracture density variations, orientations, and size. Such methods of fault identification in the Tshirege Member may be valuable means by which to help identify other tectonic zones in canyons that could be potential pathways for water infiltration.

Dransfield and Gardner (1985, 6612) integrated a variety of data to produce structure contour maps and paleogeologic maps of the pre-Bandelier-Tuff surface beneath the Pajarito Plateau. Their maps reveal down-to-the-west normal faults cutting subsurface rock units. These buried faults do not obviously displace the overlying Bandelier Tuff south of Los Alamos Canyon, indicating that most of these fault movements predate deposition of the Bandelier Tuff. More recent structure contour maps, isopach maps, and paleogeologic maps of the Pajarito Plateau are presented in Davis et al. (1996, 55446) and Broxton and Reneau (1996, 55429).

2.4.5 Seismicity and Volcanism

The Laboratory lies within a region that possesses a long and rich history of volcanic and tectonic activity dating from the distant past into the Late Pleistocene and present, respectively. Volcanism began in the Jemez Mountains volcanic field more than 13 million years ago and continued without

Qbt 4 is a partially welded to densely welded ignimbrite characterized by small, sparse pumices and numerous intercalated surge deposits. This unit crops out on the mesa tops in the western part of the Laboratory, but it is missing from mesa tops over the mid-to-eastern Pajarito Plateau. It forms the bedrock unit in the canyon floors along the western part of the Laboratory near the Sierra de los Valles. Devitrification and vapor-phase alteration are typical in this unit, but thin zones of vitric ignimbrite occur within the upper part of the unit near MDA P.

2.4.2.6 Post-Bandelier Units

Stratigraphically overlying the Bandelier Tuff are discontinuous Quaternary alluvial units that occur as thin deposits (typically less than 15 ft thick) on mesa tops and as deposits in canyons. Alluvial fans consisting mostly of dacite debris are being shed over the Bandelier Tuff at the western boundary of the Laboratory. Well-sorted to poorly sorted sandy and gravelly alluvium occurs in the major drainages of the Pajarito Plateau, ranging up to at least 70 ft thick in some drill holes (Baltz et al. 1963, 8402). Additional, older alluvium occurs on stream terraces on the sides of the canyons, which can be buried by colluvial deposits from the canyon walls. The distribution of alluvial deposits on the mesas has not been mapped, but these deposits are most widespread on the western part of the Pajarito Plateau. Post-Bandelier alluvial units represent a range of ages from 1.1 million years ago to the present. Generally, alluvial units on the surface of the mesas are probably oldest, becoming inactive as drainages were incised into the plateau. Those units lowest in the drainages grade into the active alluvium along canyon bottoms.

The alluvial sediments in the canyon bottoms probably record a complex history of erosion and deposition, in part related to regional climatic changes. In Cabra Canyon, immediately north of Los Alamos, several cycles of erosion and deposition of sediment have occurred over the last 6,000 years, during which most of the previously stored sediment was eroded (Gardner et al. 1990, 48813). Similar cycles of erosion and deposition have been documented in many parts of the southwestern United States, and the older alluvial units in the vicinity of Los Alamos may also record the effects of regional climatic changes (Dethier et al. 1988, 57003).

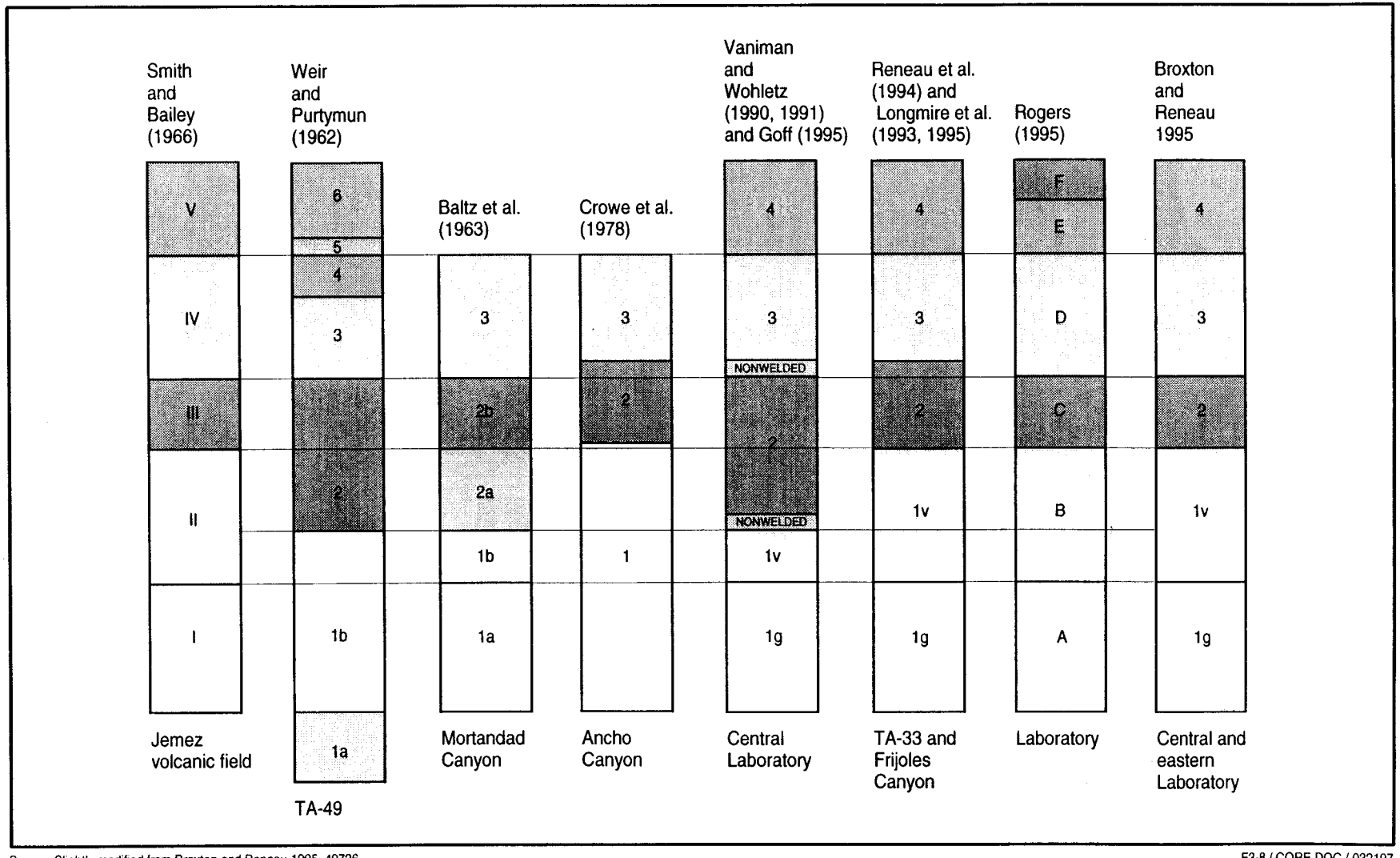
The mesas of the Pajarito Plateau are also covered in part by deposits of the El Cajete pumice, erupted from El Cajete crater in the Jemez Mountains. Deposits of pumice on the mesas have been mapped by Rogers (1995, 54419). They are generally most common in the southern part of the Laboratory, and the axis of the volcanic dispersal plume is south of Los Alamos County. Available data suggest that the El Cajete pumice is 50,000 to 60,000 years old (Toyoda et al. 1995, 57001; Reneau et al. 1996, 57002).

Pre-El Cajeta, post-Bandelier pumice falls and reworked tuffs have been recently recognized at a number of sites on the Pajarito Plateau. These pumice beds are believed to be associated with eruptions of the Deer Creek and Valle Grande members of the Valles Rhyolite of Bailey et al. (1969, 21498) and Smith et al. (1970, 9752).

2.4.3 Soils

Soils on the Pajarito Plateau were initially mapped and described by Nyhan et al. (1978, 5702. The Nyhan study included only Laboratory-controlled lands and certain United States (US) Forest Service lands within Los Alamos County.

The soils were formed in a semiarid climate and were derived from chemical, biological, and physical weathering of local bedrock units, fallout pumice deposits, eolian deposits, and sediments derived from these geological materials (Nyhan et al. 1978, 5702). A large variety of soils have developed on the Pajarito Plateau as the result of interactions of the underlying bedrock, slope, and climate. The



Source: Slightly modified from Broxton and Reneau 1995, 49726

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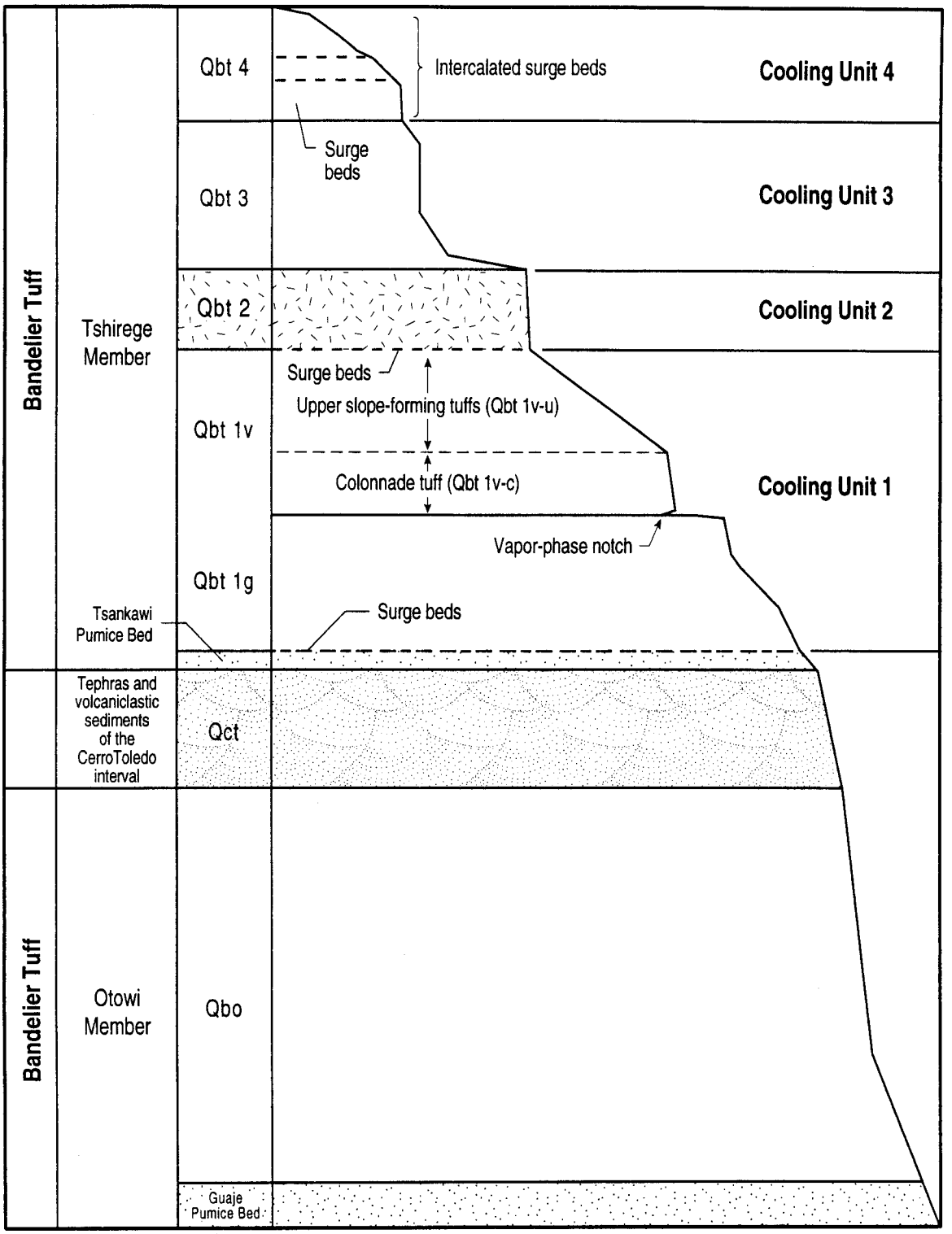
Figure 2-12. Correlation of rock unit names applied to the Tshirege Member of the Bandelier Tuff.



Source: Broxton and Reneau 1995, 49726

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Figure 2-11. Illustration of the Bandelier Tuff weathering profile and unit subdivisions.

The Tshirege Member can be divided into mappable subunits (Figure 2-11) based on a combination of hydrologic properties and lithologic characteristics. There is a certain amount of confusion due to the inconsistent use of subunit names for the Tshirege Member (Baltz et al. 1963, 8402; Weir and Purtymun 1962, 11890; Crowe et al. 1978, 5720; Vaniman and Wohletz 1990, 21589; Vaniman 1991, 9995; Goff 1995, 49682; Broxton et al. 1995, 50121). Figure 2-12 shows correlations of subunit designations applied by various workers. To avoid such confusion, this discussion follows the nomenclature of Broxton and Reneau (1995, 49726), which has been adopted by the ER Project.

Broxton et al. (1995, 50121) provide extensive descriptions of the Tshirege Member cooling units. Because the canyons crossing the Pajarito Plateau cut through the Tshirege Member with increasing depth to the east, all of these units crop out at some point in the floors and walls of most canyons. Also, the degree of welding in each of the cooling units generally decreases from west to east, reflecting the higher emplacement temperatures near the tuff's source in the Valles caldera. Densely welded in the Sierra de los Valles, the Tshirege Member shows a gradual decrease in welding eastward, such that only cooling unit 2 shows much welding in most canyons of the Laboratory. The follow paragraphs describe, in ascending order, subunits of the Tshirege Member.

The Tsankawi Pumice Bed forms the base of the Tshirege Member. Where exposed, it is commonly 20 to 30 in. (51 to 76 cm) thick. This pumice-fall deposit contains moderately well sorted pumice lapilli (diameters reaching about 2.5 in. [6.4 cm]) in a crystal-rich matrix. Several thin ash beds are interbedded with the pumice-fall deposits.

Qbt 1g is the lowermost subunit of the thick ignimbrite sheet overlying the Tsankawi Pumice Bed. It consists of porous, nonwelded, and poorly sorted ash flow tuffs. The "g" in this designation stands for "glass" because none of the glass in ash shards and pumices shows crystallization by devitrification or vapor-phase alteration. This unit is poorly indurated but nonetheless forms steep cliffs because of a resistant bench near the top of the unit which forms a harder, protective cap over the softer underlying tuffs. A thin (4 to 10 in. [10 to 25 cm]), pumice-poor, surge deposit commonly occurs at the base of this unit.

Qbt 1v forms alternating cliff-like and sloping outcrops composed of porous, nonwelded, but crystallized tuffs. The "v" stands for vapor-phase crystallization, which together with *in situ* crystallization (devitrification) has converted much of the glass in shards and pumices into microcrystalline aggregates. The base of this unit is a thin, horizontal zone of preferential weathering that marks the abrupt transition from glassy tuffs below to crystallized tuffs above. This feature forms a widespread mappable marker horizon (locally termed the vapor-phase notch) throughout the Pajarito Plateau, which is readily visible in many canyon walls. The lower part of this unit is orange brown, resistant to weathering, and has distinctive columnar (vertical) joints; hence the term colonnade tuff is appropriate for its description. A distinctive white band of alternating cliff- and slope-forming tuffs overlies the colonnade. The tuffs of Qbt 1v are commonly nonwelded (pumices and shards retain their initial equant shapes) and have an open, porous structure.

Qbt 2 forms a distinctive, medium brown, vertical cliff that stands out in marked contrast to the slope-forming, lighter colored tuffs above and below. A series of surge beds commonly mark its base in the eastern part of the Laboratory, and it displays the greatest degree of welding in the Tshirege Member. It is typically nonporous and has low permeability relative to the other units of the Tshirege Member. Vapor-phase crystallization of flattened shards and pumices is extensive in this unit.

Qbt 3 is a nonwelded to partially welded, vapor-phase altered tuff, which forms many of the upper cliffs in the mid-to-lower reaches of canyons on the Pajarito Plateau. Its base consists of a purple gray, unconsolidated, porous, and crystal-rich nonwelded tuff that underlies a broad, gently sloping bench developed on top of Qbt 2. This basal, nonwelded portion forms relatively soft outcrops that weather into low, rounded mounds with a white color, which contrast with the cliffs of partially welded tuff in the middle and upper portions of Qbt 3.

The Guaje Pumice Bed occurs at the base of the Otowi Member, making a significant and extensive marker horizon in many well boreholes. The Guaje Pumice Bed (Bailey et al. 1969, 21498; Self et al. 1986, 21579) contains well-sorted pumice fragments whose mean size varies between 0.8 and 1.6 in. (2.0 and 4.1 cm). Its thickness averages ~28 ft (~8.5 m) below most of the plateau with local areas of thickening and thinning. Its distinctive white color and texture make it easily identifiable in well borehole cuttings and core, and it is an important marker bed for the base of the Bandelier Tuff.

2.4.2.5.2 Tephras and Volcaniclastic Sediments of the Cerro Toledo Interval

The Cerro Toledo interval is an informal name given to a sequence of volcaniclastic sediments and tephras of mixed provenance that separates the Otowi and Tshirege Members of the Bandelier Tuff (Broxton et al. 1995, 50121; Goff 1995, 49682; Broxton and Reneau 1995, 49726). Although it is intercalated between the two members of the Bandelier Tuff, it is not considered part of that formation (Bailey et al. 1969, 21498). Outcrops of the Cerro Toledo interval generally occur wherever the top of the Otowi Member appears in Los Alamos Canyon and in canyons to the north. The unit contains primary volcanic deposits normally assigned to the Cerro Toledo Rhyolite as described by Smith et al. (1970, 9752) as well as intercalated and reworked volcaniclastic sediments not normally included in the Cerro Toledo Rhyolite. The occurrence of the Cerro Toledo interval is widespread; however, its thickness is variable ranging from several feet to more than 100 ft (30.5 m) thick.

The predominant rock types in the Cerro Toledo interval are rhyolitic tuffaceous sediments and tephra (Stix et al. 1988, 49680; Heiken et al. 1986, 48638; Broxton et al. 1995, 50121; Goff 1995, 49682). The tuffaceous sediments are the reworked equivalents of Cerro Toledo Rhyolite tephra that erupted from the Cerro Toledo and Rabbit Mountain rhyolite domes (see Figure 2-7) located in the Sierra de los Valles. Primary pumice-fall and ash-fall deposits occur in some locations. The pumice falls tend to form porous and permeable horizons within the Cerro Toledo interval, and locally they may provide important pathways for moisture transport in the vadose zone. Clast-supported gravel, cobble, and boulder deposits made up of porphyritic dacite derived from the Tschicoma Formation are interbedded with the tuffaceous rocks, and in some deposits, dacitic materials are volumetrically more important than rhyolitic detritus. These coarse dacitic deposits are generally confined to areas near the axes of paleochannels (Broxton and Reneau 1996, 55429; Broxton et al. 1995, 50121; Goff 1995, 49682).

2.4.2.5.3 The Tshirege Member

The Tshirege Member is the upper member of the Bandelier Tuff and is the most widely exposed bedrock unit of the Pajarito Plateau (Griggs 1964, 8795; Smith and Bailey 1966, 21584; Bailey et al. 1969, 21498; Smith et al. 1970, 9752). Emplacement of this unit occurred during eruptions of the Valles caldera ~1.2 Ma ago (Izett and Obradovich 1994, 48817; Spell et al. 1996, 55542). The Tshirege Member is a multiple-flow, ash-and-pumice sheet that forms the prominent cliffs in most of canyons on the Pajarito Plateau. It also underlies the canyon floor in all but the middle and lower reaches of Los Alamos Canyon and in canyons to the north. The Tshirege Member is generally over 200 ft (61 m) thick. Its thickness exceeds 600 ft (183 m) near the southern edge of the Laboratory at TA-49 but is thinner (often <200 ft [<61 m]) to the north and east (Broxton and Reneau 1996, 55429).

The Tshirege Member differs from the Otowi Member most notably in its generally greater degree of welding compaction. Time breaks between the successive emplacement of flow units caused the tuff to cool as several distinct cooling units. For this reason the Tshirege Member is a compound cooling unit, consisting of at least four cooling subunits that display variable physical properties vertically and horizontally (Smith and Bailey 1966, 21584; Crowe et al. 1978, 5720, Broxton et al. 1995, 50121). These variations in physical properties reflect zonal patterns of varying degree of welding and glass crystallization that accompanies welding (Smith 1960, 48819; Smith 1960, 48820). The welding and crystallization variability in the Tshirege Member produce recognizable vertical variations in its properties such as density, porosity, hardness, composition, color, and surface weathering patterns.

the five units of the basaltic rocks of Chino Mesa (Griggs 1964, 8795). Some of the older basalt flows that have been included in this formation may belong to the Santa Fe Group.

The basaltic rocks of the Cerros del Rio volcanic field form thick lava flows separated by interflow breccia, scoria, and ash. The lavas were erupted from numerous vents both east and west of the Rio Grande. In the vicinity of the Pajarito Plateau, these basalts form a north-south trending highland (now buried by the Bandelier Tuff) extending from the western edge of White Rock to the confluence of Los Alamos and Pueblo Canyons (Broxton and Reneau, 1996, 55429). These basalts are interbedded with the upper part of the fanglomerate facies of the Puye Formation. Griggs (1964, 8795) identified five lava-flow units (see Figure 3-5). The lower unit, Unit 1, crops out near river level in White Rock Canyon. Unit 2 overlies Unit 1 and forms the main cliffs along White Rock Canyon. It is the most prominent basalt found in boreholes below the central and eastern portions of the plateau, reaching a maximum thickness of 500 ft (152 m) in well PM-4. Unit 3 includes a series of flows emplaced in old stream channels, cropping out in lower Los Alamos Canyon, Sandia Canyon, and Mortandad Canyon. Unit 4 consists of two lava flows that cap the mesa south of lower Los Alamos Canyon where they overlie the Puye and Tesuque Formations. Unit 5 comprises cinder cones and surface basalt flows on Chino Mesa and on the mesa between lower Ancho Canyon and Chaquehui Canyon.

The basaltic rocks of the Cerros del Rio volcanic field include buried remnants of maar volcanoes in White Rock Canyon (Aubele, 1978, 54426; Heiken et al. 1989, 54425). The aprons of fragmental debris surrounding these buried craters consist of thin layers of basaltic ash and sediments. The maar deposits resulted from steam explosions that occurred where basalt erupted through an aquifer or standing body of water.

2.4.2.5 The Bandelier Tuff

The Bandelier Tuff consists of the Otowi and Tshirege Members, which are stratigraphically separated in many places by the tephras and volcaniclastic sediments of the Cerro Toledo interval. The Bandelier Tuff was emplaced during cataclysmic eruptions of the Valles caldera between 1.61 and 1.22 Ma ago. It is perhaps one of the best studied tuff units in the world, and it has been the subject of numerous geological studies since the early 1960s. The tuff is composed of pumice, minor rock fragments, and crystals supported in an ashy matrix. It is a prominent cliff-forming unit because of its generally strong consolidation. In the Tshirege Member, this consolidation is largely due to compaction and welding at high temperatures after the tuff was emplaced. Its light brown, orange brown, purplish, and white cliffs have numerous, mostly vertical fractures (called joints) that show average spacing of between several feet and several tens of feet. The Tshirege Member includes thin but distinctive layers of bedded sand-sized particles, called surge deposits, that demark separate flow units within the tuff. Most Laboratory facilities are located on the tuff, which is covered by thin discontinuous soils on mesa tops and alluvial deposits of variable thickness on canyon floors. Because the Bandelier Tuff is the most prominent rock type on the Pajarito Plateau, its detailed stratigraphy is of considerable importance and is discussed further below (see also Broxton and Reneau 1995, 49726).

2.4.2.5.1 The Otowi Member

The Otowi Member crops out in several canyons but is most extensive in Los Alamos Canyon and in canyons to the north. Griggs (1964, 8795), Smith and Bailey (1966, 21584), Bailey et al. (1969, 21498), and Smith et al. (1970, 9752) are important references describing the nature and extent of the Otowi Member. It consists of moderately consolidated (indurated), porous, and nonwelded vitric tuff (ignimbrite), that forms gentle, colluvium-covered slopes along the base of canyon walls. The Otowi ignimbrites contain light gray-to-orange pumice, supported in a white-to-tan ash matrix (Broxton et al. 1995, 50119; Broxton et al. 1995, 50121; Goff 1995, 49682). The ash matrix consists of glass shards, broken pumice and crystal fragments, and fragments of perlite.

2.4.2.3.1 Axial Facies of the Puye Formation

The axial facies of the Puye Formation (also called "Totavi Lentil" or "Totavi Formation") overlies the Santa Fe Group and crops out at Totavi and in areas to the east in lower Los Alamos Canyon and within White Rock Canyon to the south (Griggs 1964, 8795). It is generally ~50 ft (~15 m) thick under the eastern Pajarito Plateau but thickens in a northwest direction. It consists of coarse, poorly consolidated conglomerate containing cobbles and boulders of quartzite, granite, and pegmatite. The axial facies forms the oldest deposits in the Puye Formation in many areas but also interfingers with the lower part of the fanglomerate facies.

The axial facies is thought by many geologists to represent ancestral Rio Grande channel gravels and is believed to be a separate unit from either the finer grained Chamita Formation or the fanglomerate facies of the Puye Formation, resulting in considerable disagreement on the preferred nomenclature for this unit. It is a channel fill deposit as opposed to an alluvial fan deposit, which characterizes most of the overlying fanglomerate facies, and its composition is more akin to the Chamita Formation than to the fanglomerate facies, which is of dominantly volcanic rock types. For these reasons Turbeville et al. (1989, 21587) distinguished the Totavi deposits from the Puye Formation and assigned them a formation rank. However, because the stratigraphic uncertainties are not yet fully resolved, this document retains the assignment of these rocks to the Puye Formation as originally defined by Griggs (1964, 8795). The age of the axial facies is poorly constrained but is probably between 2.4 and 3.5 Ma (Turbeville et al. 1989, 21587).

2.4.2.3.2 Fanglomerate Facies of the Puye Formation

The fanglomerate facies is the dominant unit of the Puye Formation beneath most of the Laboratory areas. Fanglomerate is a general term meaning a rock unit composed of conglomerates deposited in an alluvial fan setting. The fanglomerate facies contains angular-to-subangular cobbles and boulders of latite, quartz latite, dacite, rhyolite, and tuff in a matrix of silts, clays, and sands. Lenses of silt, clay, and pumice are common. It is interbedded with basaltic rocks of the Cerros del Rio volcanic field in the eastern and central part of the Laboratory. The fanglomerate facies is widespread beneath the Pajarito Plateau and caps the prominent cliffs (Puye Escarpment) along the Rio Grande north of Otowi Bridge.

2.4.2.3.3 Lacustrine Facies of the Puye Formation

Griggs (1964, 8795) included lake beds (the lacustrine facies) as the uppermost part of the Puye Formation. He differentiated them from the fanglomerate facies based on the presence of lake clays and ancient stream gravels that fill channels cut into the fanglomerates. Basaltic rocks of the Cerros del Rio volcanic field are also found in these channels (Griggs 1964, 8795). The lacustrine facies is present in lower Los Alamos Canyon and extends both northward and southward in discontinuous outcrops for several miles. However, it is apparently of limited extent beneath the Pajarito Plateau, being reported only in the borehole for well PM-1 near the eastern edge of the plateau.

2.4.2.4 Basaltic Rocks of the Cerros del Rio Volcanic Field ("Basaltic Rocks of Chino Mesa")

The basaltic rocks of the Cerros del Rio volcanic field crop out primarily on the eastern side of the Rio Grande, and occur in the subsurface below much of the Pajarito Plateau (Dransfield and Gardner 1985, 6612; Broxton and Reneau 1996, 55429). Outcrops within the Laboratory area occur in most canyons along the southern and eastern margins of the plateau. The stratigraphic nomenclature for these basalts has varied with different workers (e.g., Smith et al. 1970, 9752; Kelley 1978, 11659; Griggs 1964, 8795; Aubele 1978, 54426; Galusha and Blick 1971, 21526). Kelley (1978, 11659) mapped four different units of the Cerros del Rio Basalts, one of which (the Cubero Basalts) includes

2.4.2.2 The Tschicoma Formation

The Tschicoma Formation of the Polvadera Group makes up the rugged highlands west of Los Alamos and crops out in the headwaters of the larger canyons that cut the Pajarito Plateau. Deep well boreholes along the western perimeter of the Laboratory intersect this unit at depths of several hundred feet or more, but the Tschicoma Formation is generally absent in boreholes penetrating the central and eastern parts of the Laboratory.

The Tschicoma Formation consists of numerous thick lava flows derived from a series of volcanic domes that predate the Bandelier Tuff. Fragmental deposits of ash and lava debris occur in the distal parts of the formation. It has a variable thickness due to the lenticular shape of its lava flows, and is at least 2,500 ft (762 m) thick in the Sierra de los Valles. The Tschicoma Formation thins eastward under the Bandelier Tuff on the Pajarito Plateau where it interfingers with the penecontemporaneous Puye Formation. The lower parts of the Tschicoma Formation may interfinger with the upper Santa Fe Group.

Tschicoma Formation lava flows range in composition from andesite to low-silica rhyolite but are dominantly dacites. The rocks are mainly gray to purplish gray, but in places they are reddish brown. These flows display pronounced jointing and have bottoms commonly marked by blocky breccia. Lavas contain glassy and microcrystalline groundmass; the glass is generally devitrified giving the rocks a stony appearance.

Radiometric ages for the Tschicoma Formation in the vicinity of Los Alamos range between 3.7 and 6.7 Ma (Dalrymple et al. 1967, 49924). Turbeville et al. (1989, 21587) report an age of 2.53 Ma for a Tschicoma ignimbrite within the Puye Formation. In the northern part of the Jemez volcanic field, the Tschicoma Formation is bracketed in age by the underlying Lobato Basalt (7.4 Ma) and the overlying El Rechuelos Rhyolite (2.0 Ma) (Loeffler et al. 1988, 54409).

2.4.2.3 The Puye Formation

The Puye Formation is a large apron of alluvial fans which were shed eastward from the Jemez volcanic field into the Española basin, covering the Santa Fe Group rocks west of and along the Rio Grande. Intersected by most deep water wells on the Pajarito Plateau (Dransfield and Gardner 1985, 6612; Purtyman 1995, 45344), this formation crops out in canyons north of Los Alamos Canyon. Turbeville et al. (1989, 21587) estimated its areal distribution at 200 km^2 (518 mi^2) and its volume at ~15 km^3 (~3.6 mi^3). Its age is generally placed at between 1.9 and 3.5 Ma, but it may be as young as 1.6 Ma and as old as 6.7 Ma because of its expected temporal and spatial association with eruption of the Tschicoma Formation. The lithology of the Puye Formation is dominated by conglomerates and gravels consisting of subrounded dacitic and andesitic lava clasts in a sandy matrix. At least 25 ash beds of dacitic to rhyolitic composition are interbedded with the conglomerates and gravels (Turbeville et al. 1989, 21587), and basaltic ash and lacustrine layers are present along the eastern margins of this formation. Showing considerable lateral variation in textures and composition, the formation reaches a maximum thickness of ~700 ft (~213 m) in Pueblo Canyon (Griggs 1964, 8795) but thins to 50 ft (15 m) in areas north of the Pajarito Plateau (Dethier and Manley 1985, 21506). In the central and eastern portions of the Laboratory, it is ~600 ft (~183 m) thick and is interbedded with basaltic lavas of the Cerros del Rio volcanic field. The Puye Formation as defined by Griggs (1964, 8795) originally included three units, in ascending order: an axial facies (called the "Totavi Lentil" by Griggs [1964, 8795]); a fanglomerate facies; and a lacustrine facies (called "older alluvium" by Griggs [1964, 8795]) (Figure 2-9 and Figure 2-10).

45344) has also given the name "Chaquehui Formation" to distinctive coarse-grained sediments at the top of the Santa Fe Group on the Pajarito Plateau based on evidence from deep well boreholes on the Pajarito Plateau.

"Chaquehui Formation" is not a formal geologic name at present and there is disagreement among geologists as to whether it should be recognized separately from the Chamita Formation.

2.4.2.1.1 The Tesuque Formation

The Tesuque Formation is a massive, thick unit consisting of arkosic sediments, derived primarily from Precambrian basement and Tertiary volcanic sources to the east and northeast of the Española basin. This unit is a light pink-to-buff siltstone and silty sandstone with a few lenses of pebbly conglomerate and clay. It is poorly to moderately consolidated and has an age range of about 7 to 21 Ma (Manley, 1979, 11714; Cavazza 1989, 21501). Spiegel and Baldwin (1963, 54259) describe the Tesuque Formation at the southern end of the Española basin, including the exposures in the vicinity of Otowi Bridge and along White Rock Canyon. This formation exists in deep well boreholes under the Pajarito Plateau and is the primary aquifer for municipal and industrial water supply in Los Alamos County. The Tesuque Formation contains basalt at a depth of 2,219 ft (67.6 m) in Otowi well O-1 (Purtymun 1995, 45344).

2.4.2.1.2 The Chamita Formation

The Chamita Formation overlies and interfingers with the Tesuque Formation. It consists of arkosic siltstones, sandstones, pebbly conglomerate, and includes two prominent beds of white ash. This formation is thickest in the northern part of the Española basin and thins to less than 30 ft (9.1 m) or is absent under most of the Laboratory. Aldrich and Dethier (1990, 49681) suggest that the Chamita Formation north of the Pajarito Plateau may be as old as 12 Ma and the age estimates for the overlying "Chaquehui Formation" (see below) support that suggestion. However, paleomagnetic data in the area indicate an age range of 4.5 to 6 Ma (MacFadden 1977, 21569), and tephra dates by Manley (1979, 11714) support a younger age of about 5 Ma for at least part of the formation. Because the Chamita and Tesuque Formations may not be distinguishable in borehole cores and cuttings, it is sometimes necessary to group these formations as "undifferentiated Santa Fe Group" during borehole investigations.

2.4.2.1.3 The "Chaquehui Formation"

Sedimentary deposits referred to as the "Chaquehui Formation" by Purtymun (1995, 45344), and shown as upper facies of the Santa Fe Group on Figure 2-9 and Figure 2-10, are made up of mixtures of volcanic debris from the Jemez Mountains and arkosic materials from the highlands to the north and east. Because of their coarse-grained nature, these rocks are an important aquifer for municipal and industrial water supply in the Los Alamos area (Purtymun 1995, 45344). The "Chaquehui Formation" overlies the Chamita Formation in well boreholes on the Pajarito Plateau. However, because it contains interbedded basalt lava flows dated at 8 to 9 Ma (Laughlin et al. 1993, 54424), it is equivalent in age to older parts of the Chamita Formation. The "Chaquehui Formation" forms a transitional interval between older Santa Fe Group rocks and overlying volcaniclastic rocks derived from the Jemez Mountains. The presence of coarse-grained arkosic materials within the "Chaquehui Formation" suggests that these deposits may represent axial deposits of an ancestral Rio Grande within the Chamita Formation.

correlations, and radiometric measurements provide the approximate ages of most of the bedrock units. The bedrock units and their ranges of approximate radiometric ages are listed below in ascending order.

1. Santa Fe Group: 4 to 21 Ma (Manley 1979, 11714)

2. Tschicoma Formation: 2.53 to 6.7 Ma (Dalrymple et al. 1967, 49924)

3. Puye Formation: 1.7 to 4 Ma (Turbeville et al. 1989, 21587; Spell et al. 1990, 21586), which includes a fanglomerate facies, an axial facies (Manley 1979, 11714; Turbeville et al. 1989, 21587), and a lacustrine facies

4. Basaltic rocks of the Cerros del Rio volcanic field (also known as "basaltic rocks of Chino Mesa") (2 to 3 Ma) (Gardner and Goff 1984, 44021; WoldeGabriel et al. 1996, 54427)

5. Otowi Member of the Bandelier Tuff: 1.61 Ma (Izett and Obradovich 1994, 48817; Spell et al. 1996, 55542)

6. Volcaniclastic sediments and tephras of the Cerro Toledo interval

   The age of this unit is bracketed by the ages of the underlying Otowi Member (1.61 Ma) and the overlying Tshirege Member (1.22 Ma) of the Bandelier Tuff.

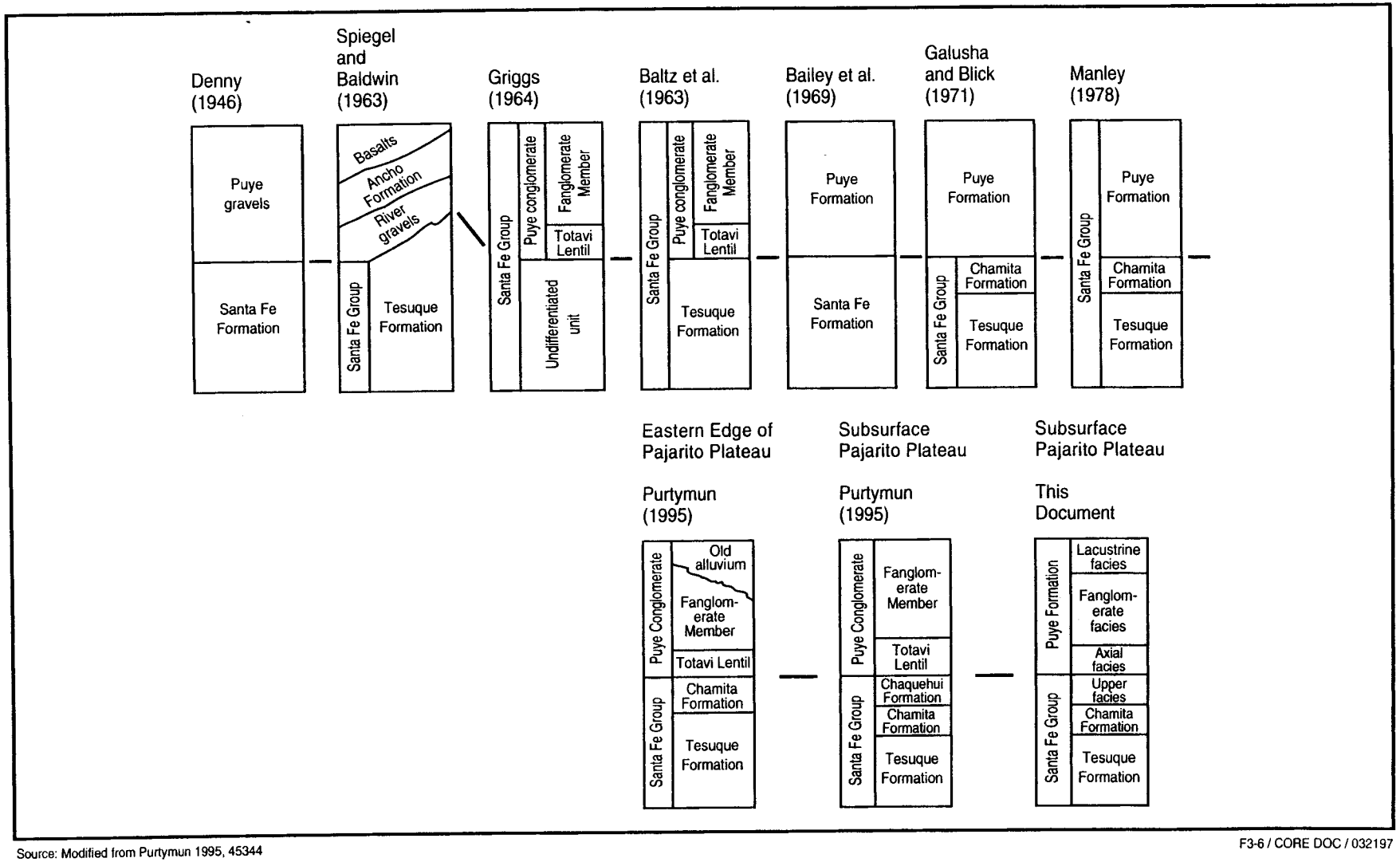
7. Tshirege Member of the Bandelier Tuff: 1.22 Ma (Izett and Obradovich 1994, 48817; Spell et al. 1996, 55542)

A geologic map published by Smith et al. (1970, 9752) shows the distribution of these bedrock units across the Pajarito Plateau. Other general geological maps covering this area are those by Griggs (1964, 8795), Kelley (1978, 11659), and Goff et al. (1990, 21574). More detailed geological maps covering portions of the Laboratory include those by Baltz et al. (1963, 8402), Rogers (1995, 54419), Vaniman and Wohletz (1990, 21589), Reneau et al. (1995, 54405), and Goff (1995, 49682). Figure 2-7 shows area locations, and Figure 2-9 and Figure 2-10 illustrate the stratigraphic units referred to in the following sections.

2.4.2.1 The Santa Fe Group

Rocks of the Santa Fe Group crop out in lower Los Alamos Canyon, near the mouth of Guaje Canyon, and along the margins of the Rio Grande from Otowi Bridge south to White Rock. Galusha and Blick (1971, 21526) subdivided the Santa Fe Group into formations and members based on geologic mapping and fossil assemblages of late Tertiary mammals (Figure 2-10). Manley (1979, 11714) refined the stratigraphy of the Santa Fe Group with additional mapping and dates of interbedded volcanic ash layers, lava flows, and dikes. The description herein (see Figure 2-9 and Figure 2-10) follows the nomenclature of Galusha and Blick (1971, 21526) as modified by Manley (1979, 11714) and Purtymun (1995, 45344).

In the vicinity of the Pajarito Plateau, the stratigraphy and geochronology of the Santa Fe Group is poorly understood because of the near continuous blanket of younger volcanic deposits. Based on exposures near the Rio Grande, the Santa Fe Group beneath the Pajarito Plateau is believed to include, in ascending order, the Tesuque Formation and the Chamita Formation. Purtymun (1995,



Source: Modified from Purtymun 1995, 45344

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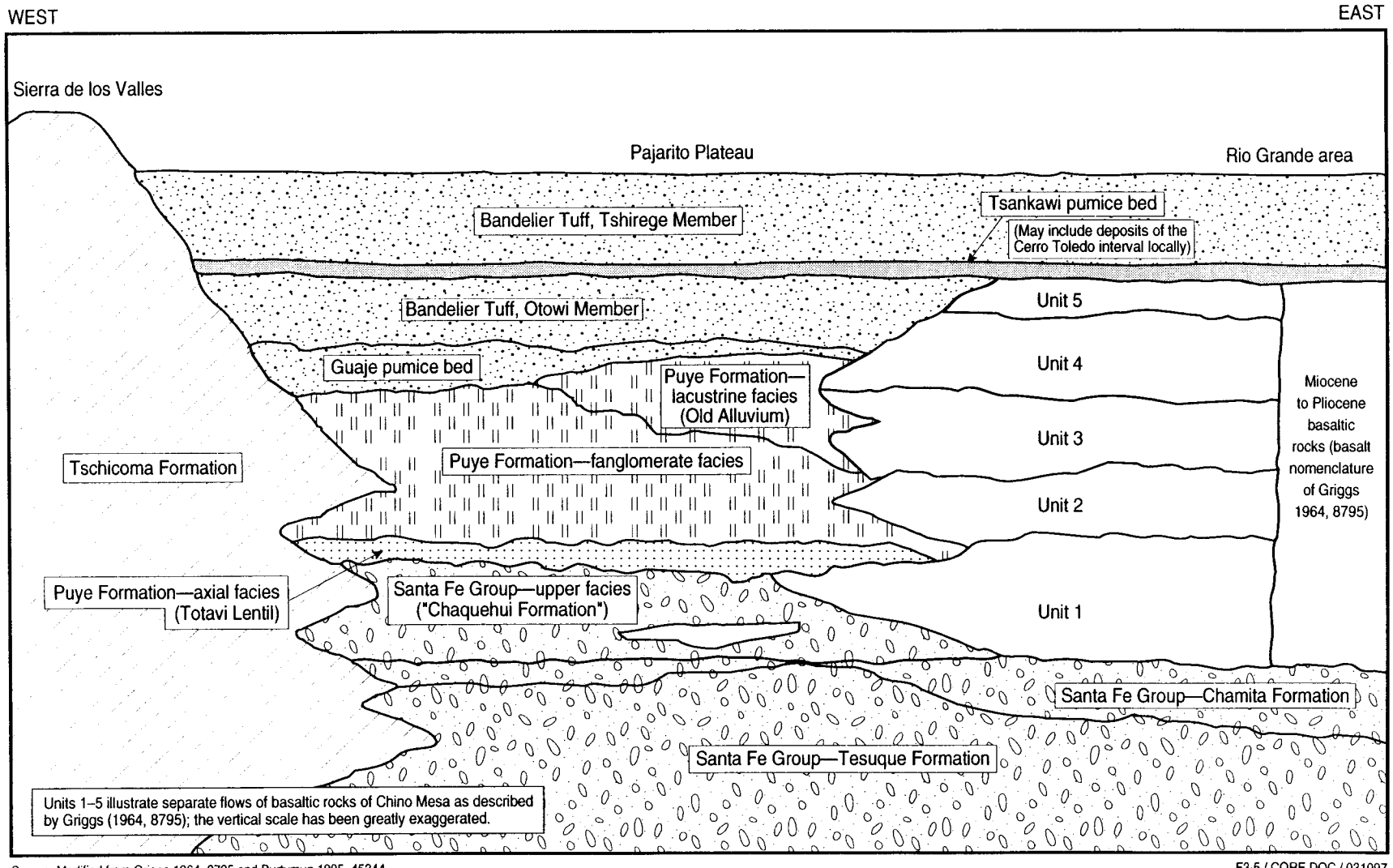
Figure 2-10. Stratigraphic relationships and evolution of nomenclature for pre-Bandelier Tuff rocks of the Pajarito Plateau.



Source: Modified from Griggs 1964, 8795 and Purtymun 1995, 45344

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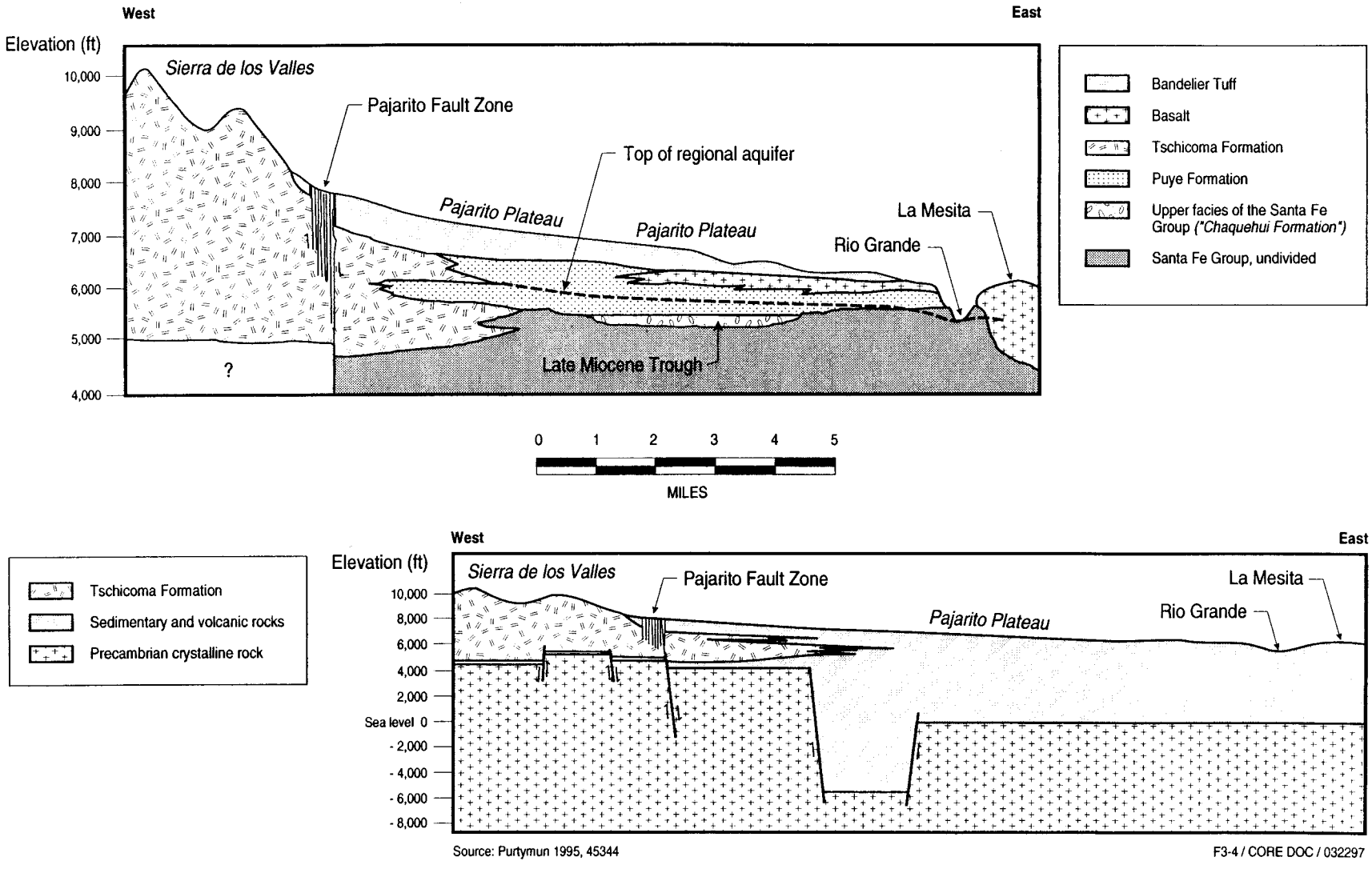
Figure 2-9. Schematic cross section of the Pajarito Plateau showing complex interfingering of volcanic and sedimentary rocks.



Source: Purtymun 1995, 45344

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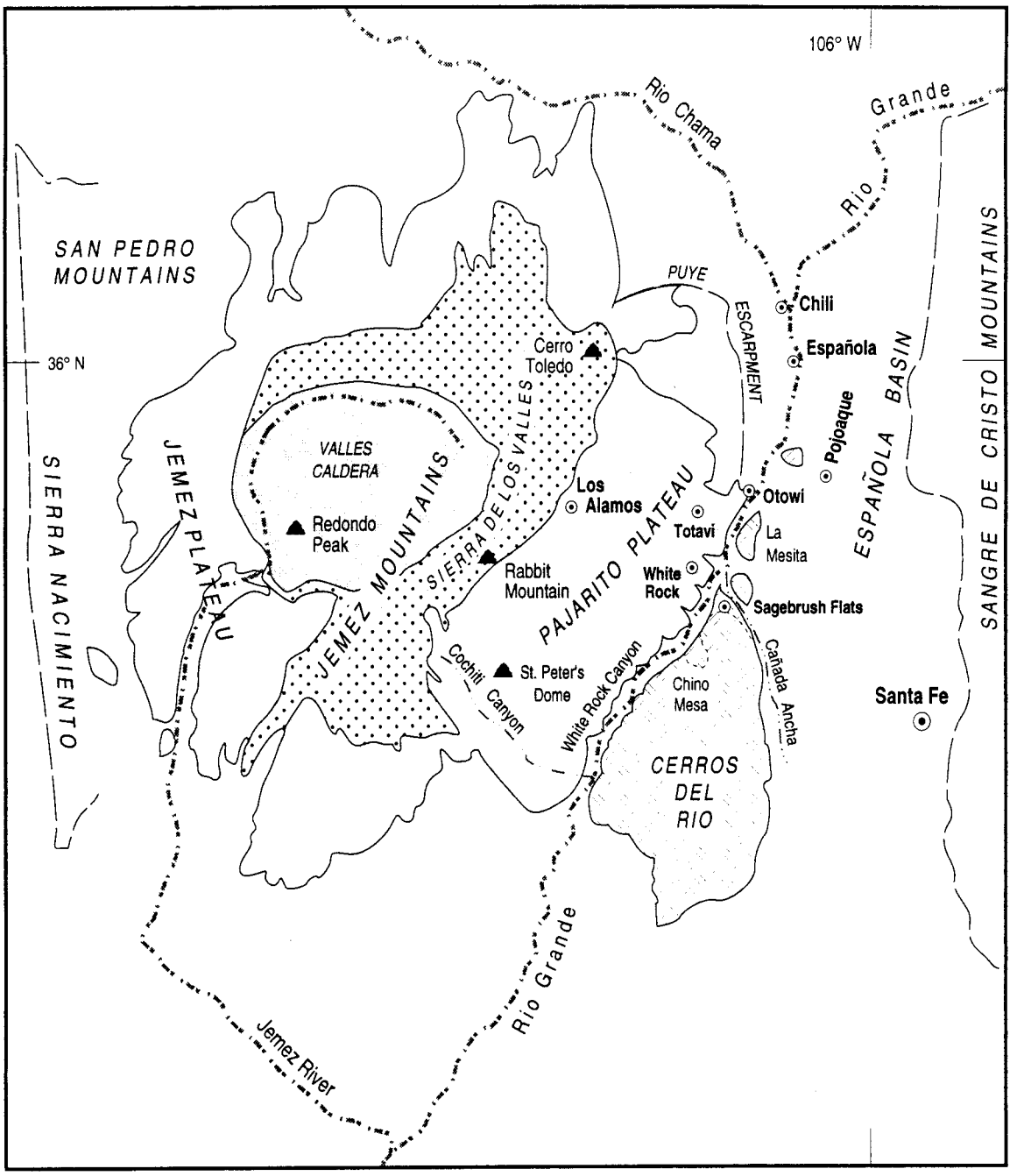
Figure 2-8. Generalized geologic cross sections of the Pajarito Plateau.



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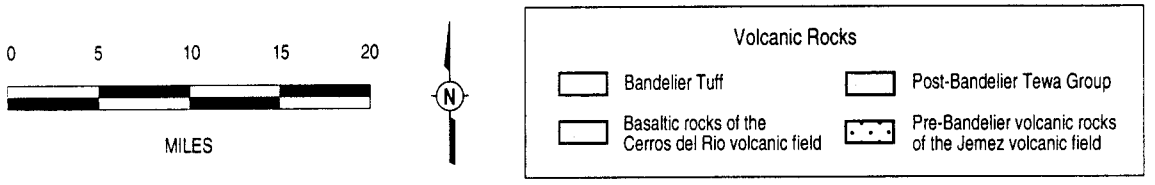

Figure 2-7. General geologic and geographic features of the Pajarito Plateau and surrounding area.

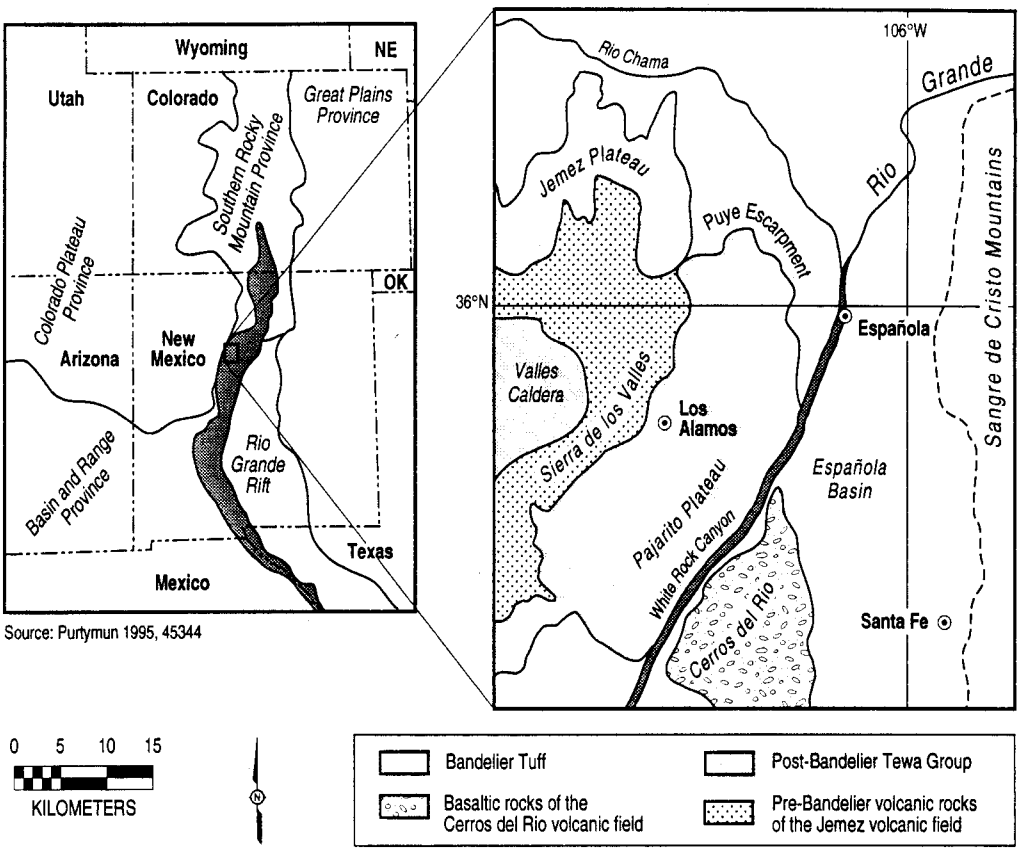

Figure 2-6. Physiographic features of the Pajarito Plateau.

Figure 2-7 is a general geologic map highlighting the dominantly volcanic rock types of the area. The gently east-sloping Bandelier Tuff covers the Pajarito Plateau (Figure 2-8). Deep canyons are incised into the Bandelier Tuff and expose it to depths of up to several hundred feet below the general level of the plateau. From west to east, these canyons cut progressively deeper into the Bandelier Tuff and, near the Rio Grande, some of the deeper canyons expose older lavas and sedimentary rocks. Figure 2-9 and Figure 2-10 schematically portray the complex interfingering of volcanic rocks and sediments that occurs below the Bandelier Tuff. Volcanic rocks of the Tschicoma Formation and their derivative sediments (fanglomerate facies of the Puye Formation) extend eastward under the plateau where they interfinger with Santa Fe Group rocks and basaltic rocks of the Cerros del Rio volcanic field (also called "basaltic rocks of Chino Mesa").

2.4.2 Stratigraphy

The following descriptions cover the rock units relevant to the ER investigations, starting with the oldest (deepest) and proceeding to the youngest (topmost). Fossil evidence, stratigraphic

TABLE 2-1

1992 POPULATION WITHIN 80 KM OF LOS ALAMOS

	Distance from TA-53 (km)								
Direction	1–2	2–4	4–8	8-15	15–20	20–30	30–40	40–60	60–80
N	1	0	0	0	0	0	1,169	0	378
NNE	0	0	0	582	0	558	1,781	1,850	227
NE	1	0	0	0	326	15,860	1,039	1,170	3,965
ENE	0	0	0	2,031	1,609	2,843	2,827	1,222	2,267
E	0	0	87	26	582	1,199	728	0	1,422
ESE	0	0	0	0	0	306	24,239	1,091	1,511
SE	0	0	6,796	0	0	0	56,036	2,558	8
SSE	0	0	0	0	0	0	446	4,551	99
S	0	0	0	50	0	347	670	7,363	0
SSW	0	0	0	20	0	891	219	8,981	36,507
SW	0	0	0	0	0	0	343	4,532	0
WSW	0	0	0	0	0	343	341	2,775	225
W	0	0	0	0	0	0	0	179	144
WNW	0	1,443	6,572	0	0	0	0	0	3,359
NW	0	526	1,731	0	0	0	0	1,481	0
NNW	0	581	582	0	0	0	0	65	64
1992 Population Distribution	2	2,550	15,768	2,709	2,517	22,347	89,838	37,818	50,176

Note: Total population within 80 km of Los Alamos is 223,725.

2.4.1 Geologic Overview

The Laboratory is sited on the Pajarito Plateau, an east-sloping, dissected tableland bounded on the west by the eastern Jemez Mountains (Sierra de los Valles) and on the east by White Rock Canyon of the Rio Grande (Figure 2-6). The geology of the Pajarito Plateau reflects the interplay of volcanism in the Jemez Mountains and surrounding areas with the development of the Rio Grande rift, a series of north-south trending fault troughs extending from southern Colorado to southern New Mexico (Figure 2-6). Volcanism over the last 13 Ma (million years) has built up the highlands area of the Jemez Mountains, while the contemporaneous tectonic rifting has resulted in subsidence of the area extending from the eastern margin of the Jemez Mountains to the western margin of the Sangre de Cristo Mountains. This area of subsidence, locally termed the Española basin of the Rio Grande rift, is a graben between two larger basins—the Albuquerque basin to the south and San Luis basin to the north (Kelley 1978, 11659). During this interplay of volcanism and rifting, erosion has removed materials from the highlands areas to the west and deposited them downslope to the east into the rifted lowlands, which were contemporaneously receiving sediments from other sources. The Pajarito Plateau has developed in and now occupies the western part of the Española basin (Figure 2-6).

season. Strong daytime heating during the summer can force vertical mixing up to 3,000 to 6,000 ft above ground level, but the effectiveness of the generally light winds in diluting contaminants horizontally is limited.

Clear skies and light winds have a negative effect on nighttime dispersion, causing strong, shallow surface inversions to form. These inversions can severely restrict near-surface vertical and horizontal dispersion. Inversions are especially strong during the winter. Drainage winds can fill lower areas with cold air, thereby creating deeper inversions, which are common toward the Rio Grande valley on clear nights with light winds. Canyons can also limit dispersion by channeling air flow. Strong, large-scale inversions during the winter can limit vertical mixing to under 3,000 ft above ground level.

Dispersion is generally greatest during the spring, when winds are strongest. However, deep vertical mixing is greatest during the summer. Dispersion is generally low during summer and autumn, when winds are light. Even though low-level winter dispersion is generally greater, intense surface inversions can cause least-dispersive conditions during the night and early morning.

During the winter, the frequencies of atmospheric dispersive capability sampled at Technical Area (TA) 59 are 52% unstable (Stability Classes A through C), 21% neutral (Class D), and 27% stable (Classes E and F). The frequencies are 44%, 22%, and 34%, respectively, during the summer. These stability category frequencies are based on measured vertical wind variations. Stability generally increases (the winds become less dispersive) toward the valley.

2.3.4 Population Distribution

Los Alamos County had an estimated 1992 population of approximately 18,200, based on the 1990 census adjusted to 1992 (Environmental Protection Group 1994, 35363). Two residential areas (Los Alamos and White Rock) and their related commercial areas exist in the county (Figure 2-1). The Los Alamos townsite (the original area of development that now includes the residential areas known as Eastern Area, Western Area, North Community, Barranca Mesa, and North Mesa) has an estimated population of 11,400. The White Rock area (including the residential areas of White Rock, La Senda, and Pajarito Acres) has about 6,800 residents. About 40% of the people employed in Los Alamos commute from other counties. Population data from 1990, adjusted to 1992, place about 224,000 persons within a 50-mi radius of Los Alamos (Table 2-1) (Environmental Protection Group 1994, 35363).

2.4 Geology

This summary of the hydrogeologic environment at the Laboratory and in the northern New Mexico region is intended to describe the major geologic, hydrologic, and hydrogeologic features and their conceptual interrelationships. It addresses the regional and installation-wide geologic setting and the hydrologic characteristics that affect surface water and groundwater occurrence and movement and their interactions as they relate to the potential for contaminant transport. The sources cited here and additional literature on the hydrology and geology of the Los Alamos region may be found in an annotated bibliography of geologic, hydrogeologic, and environmental studies related to solid waste management units at the Laboratory (LANL 1990, 47588). This bibliography was submitted to EPA in September 1990. The bibliography and the literature it describes are available for review in the Laboratory's public reading room located at 1350 Central Avenue, Suite 101, in Los Alamos.

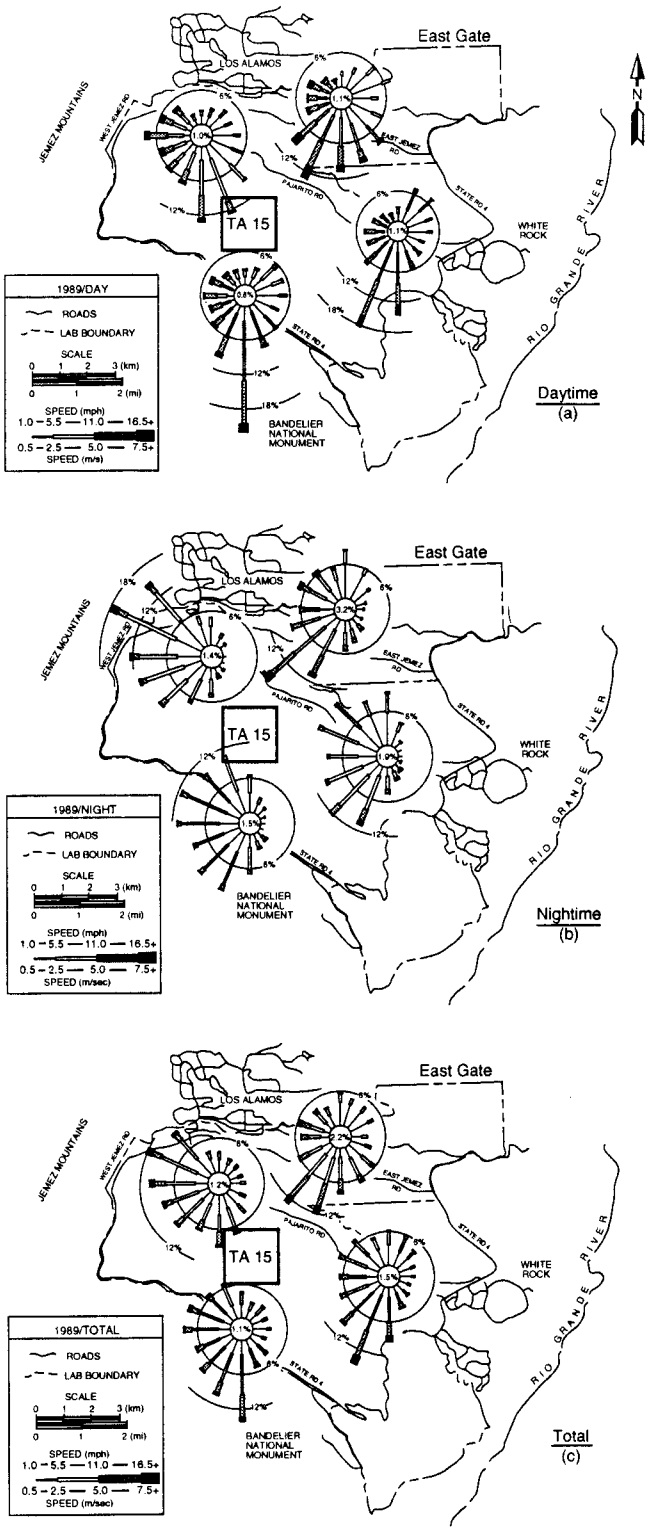

Figure 2-5. Wind roses at Laboratory stations during 1989.

Wetlands within Laboratory boundaries fall primarily into two classifications: palustrine and riverine. Palustrine wetlands (ponds and marshes) have been identified in Sandia, Pajarito, and Pueblo canyons, and smaller ones have been identified in other parts of the Laboratory. Wetlands in Sandia and Pueblo canyons are primarily maintained by effluent releases. Beds of ephemeral and intermittent streams that traverse the Laboratory have been classified as temporarily flooded riverine wetlands. In addition, the Laboratory has several small wetlands associated with outfalls that have existed long enough to have wetland vegetation associated with them.

2.3.3 Climate

Bowen (1990, 6899) has compiled and interpreted climatological data for the Los Alamos area, and this information is summarized below.

Los Alamos has a semiarid, temperate mountain climate. Forty percent of the 18-in. annual precipitation normally occurs from thundershowers during July and August. Winter precipitation falls primarily as snow, with accumulations of about 51 in. annually.

Summers are generally sunny, with moderate, warm days and cool nights. Maximum daily temperatures are usually below 90°F. Brief afternoon and evening thundershowers are common, especially in July and August. High altitude, light winds, clear skies, and dry atmosphere allow night temperatures to drop to the 50s (°F) after even the warmest day. Winter temperatures typically range from about 15°F to 25°F during the night and from 30°F to 50°F during the day. Occasionally, temperatures drop to 0°F or below. Many winter days are clear with light winds, allowing strong sunshine to make conditions comfortable even when air temperatures are cold. Snowstorms with accumulations exceeding 4 in. are common in Los Alamos, and some of these storms are associated with strong winds, frigid air, and dangerous wind chills, especially in the mountains. The climate from 1961 through 1988 had slightly cooler temperatures and higher precipitation than those recorded from 1911 through 1988 (entire record). The only significant difference between the period from 1961 through 1988 and the entire record period is the large amount of snowfall.

Because of complex terrain, surface winds in Los Alamos often vary greatly with time of day and location. With light winds and clear skies, a distinct daily wind cycle often exists: a light southeasterly to southerly upslope wind during the day and a light westerly to northwesterly drainage wind during the night (Figure 2-5, from Environmental Protection Group 1990, 6995). However, several miles to the east toward the edge of Pajarito Plateau near the Rio Grande valley, a different daily wind cycle is common: a moderate southwesterly up-valley wind during the day and either a light northwesterly to northerly drainage wind or moderate southwesterly wind at night. The predominant winds are southerly to northwesterly over western Los Alamos County and southwesterly and northeasterly toward the Rio Grande valley. Historically, no tornadoes have been reported to have touched down in Los Alamos County. Strong dust devils can produce winds up to 75 mph at isolated spots in the county, especially at lower elevations. Strong winds with gusts exceeding 60 mph are common during the spring.

Lightning is common over the Pajarito Plateau. Fifty-eight thunderstorm days occur during an average year, mostly during the summer. Lightning protection is an important design factor for most facilities at the Laboratory. Hail damage can also occur. Hailstones with diameters up to 0.25 in. are common; 0.5-in.-diameter hailstones are infrequent.

The irregular terrain at Los Alamos affects atmospheric turbulence and dispersion, sometimes favorably and sometimes unfavorably. Enhanced dispersion promotes greater dilution of contaminants released into the atmosphere. The complex terrain and forests create an aerodynamically rough surface, forcing increased horizontal and vertical dispersion. Dispersion generally decreases at lower elevations, where the terrain becomes smoother and less vegetated. The frequent clear skies and light, large-scale winds cause good vertical daytime dispersion, especially during the warm

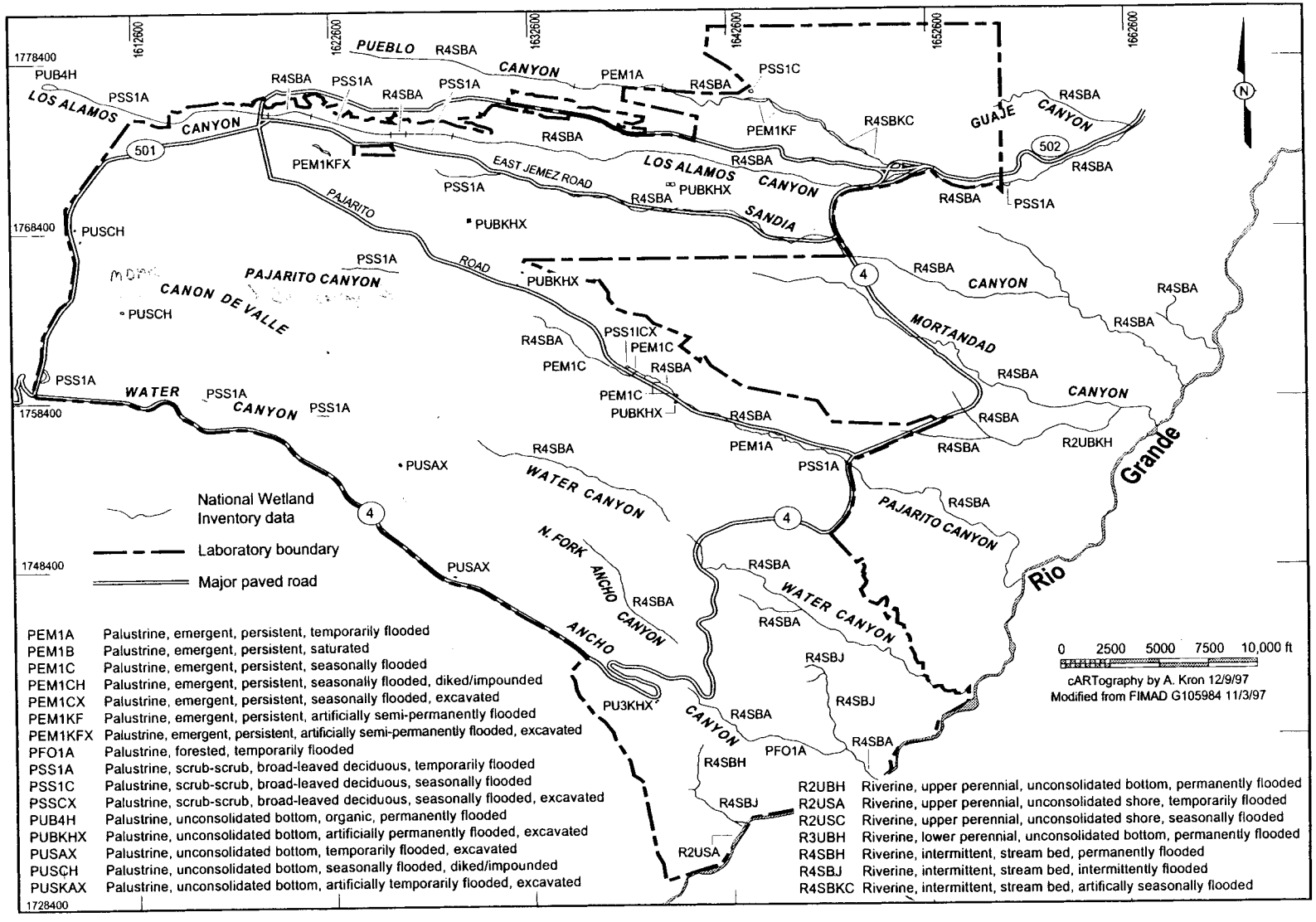

Figure 2-4. Map of wetlands.

data, biological research, and published data. Special studies are currently under way to provide a more comprehensive list of vertebrate fauna.

Based on ongoing surveys, at least four federally protected animal species, the American peregrine falcon (endangered), the bald eagle (endangered), the Mexican spotted owl (threatened), and the southwestern willow flycatcher (endangered) have been recorded on Laboratory and Los Alamos County lands.

The American peregrine falcon establishes breeding territories near cliffs in areas of mixed-conifer, ponderosa pine, and piñon pine. A historical aerie exists in the county, and American peregrine falcons are known to forage on Laboratory lands.

The bald eagle winters along the Rio Grande and has been observed over Laboratory lands. The entire Laboratory is considered suitable foraging habitat for the bald eagle.

Mexican spotted owls have been documented nesting on Laboratory lands, Bandelier National Monument, and US Forest Service lands in Los Alamos County. Nesting Mexican spotted owls inhabit canyons characterized as mixed conifer and ponderosa pine-Gamble oak forests and forage on mesa tops surrounding the canyons. Suitable habitat for this species exists throughout the Laboratory.

The southwestern willow flycatcher has been recorded during surveys in the wetlands in lower Pajarito Canyon and along the Rio Grande. To date, the southwestern willow flycatcher has been detected only during its migration and has not nested on Laboratory lands; however, suitable nesting habitat does exist at the Laboratory. Southwestern willow flycatchers inhabit areas near water with 13- to 23-ft-high thickets of willow, buttonbush, seepwillow, and tamarisk (Sogge et al. 1997, 57040).

Three other federally protected species may inhabit the Laboratory and the county and must be considered when evaluating a proposed project: the whooping crane (endangered), black-footed ferret (endangered), and Arctic peregrine (threatened). Of these three species, the Arctic peregrine and the whooping crane have been recorded in New Mexico in recent history. The black-footed ferret is extremely unlikely to be found in the state.

Several federal species of concern (formal federal candidate species) and state protected faunal species have been documented in Los Alamos County. They include the Northern Goshawk, Goat Peak pika, Jemez Mountain salamander, spotted bat, and several Myotis bat species. Other species that may occur in the area, but their presence has not been confirmed, include the New Mexico jumping mouse, loggerhead shrike, and gray vireo. (Hinojosa and Nguyen 1996, 57042).

2.3.2.3 Wetlands

Under the Resource Conservation and Recovery Act (RCRA) and the Hazardous and Solid Waste Amendments (HWSA) Module of the Laboratory's operating permit, the Environmental Protection Agency (EPA) required a determination of all wetlands located in areas that either lie within Laboratory boundaries or that drain Laboratory land (Figure 2-4).

US Fish and Wildlife personnel mapped the wetlands around Los Alamos, using US Geological Survey (USGS) quadrangle maps as base maps and infrared high-altitude aerial maps. To cover all of the watersheds that drain the Laboratory site, five quadrangles were mapped (Frijoles, White Rock, Guaje, Valle Toledo, and Puye). In addition to the watershed of the Laboratory proper, the Seven Springs quadrangle, which gives the location of the Laboratory's geothermal site at Fenton Hill, was mapped. Personnel in the Ecology group (ESH-20) have delineated and characterized individual wetlands by conducting a detailed on-the-ground and historical analysis of single sites containing wetland vegetation.

Laboratory land is used for building sites, experimental areas, waste disposal locations, roads, and utility rights-of-way. However, these uses account for only a small part of the land. Most of the land controlled by the Laboratory serves as a buffer zone for Laboratory facilities, providing security and safety to the public, and as a reserve for future construction. The Laboratory's long-range site development plan (LANL 1995, 52976) addresses the best possible future uses of available Laboratory lands.

The public is allowed limited access to certain areas of the Laboratory site. An area north of Ancho Canyon between the Rio Grande and State Road 4 is open to hikers, but woodcutting and vehicles are prohibited. Portions of Mortandad and Pueblo Canyons are also open to the public. An archaeological site (the Otowi tract), northwest of State Road 502 near the White Rock Y, is open to the public, subject to restrictions imposed by regulations to protect cultural resources.

2.3.2 Ecology

The Pajarito Plateau is a biologically diverse area. This diversity is due partly to the dramatic 5,000-ft elevation gradient from the Rio Grande to the east and the Jemez Mountains 12 mi to the west and partly to the many steep canyons that dissect the area. The pronounced east-west canyon and mesa orientations, with concomitant differences in soils, moisture, and solar radiation, produce an interlocking finger effect among ecological life zones, resulting in many transitional overlaps of plant and animal communities within small areas.

2.3.2.1 Flora

Five major vegetative cover types are found in Los Alamos County: juniper-savannah, piñon-juniper, ponderosa pine, mixed conifer, and spruce-fir. The juniper-savannah community is found along the Rio Grande on the eastern border of the plateau and extends upward on the south-facing sides of canyons, at elevations between 5,600 to 6,200 ft. The piñon-juniper cover type, generally in the 6,200- to 6,900-ft elevation range, covers large portions of the mesa tops and north-facing slopes at the lower elevations. Ponderosa pines are found in the western portion of the plateau in the 6,900- to 7,500-ft elevation range. The juniper-savannah, piñon-juniper, and ponderosa pine cover types predominate, each occupying roughly one-third of the Laboratory site. The mixed conifer cover type, at an elevation of 7,500 to 9,500 ft, overlaps the ponderosa pine community in the deeper canyons and on north slopes and extends from the higher mesas onto the slopes of the Jemez Mountains. The subalpine grassland is at higher elevations of 9,500 to 10,500 ft. Twenty-seven wetlands and several riparian areas enrich the diversity of plant and animals found on Laboratory lands.

2.3.2.2 Fauna

Before the Laboratory was established, Native Americans and European settlers farmed the mesas, disturbing areas that are now in various stages of succession. These areas afford suitable feeding locations for herbivores, especially mule deer and Rocky Mountain elk. Adjacent timbered canyon slopes provide protective cover for these species. Large mammals such as black bear, coyote, gray fox, mountain lion, and bobcat range in large areas of the Laboratory through numerous habitat types. Sheer canyon walls at all elevations serve as important nesting and foraging habitats for birds of prey. Generally, smaller mammals, songbirds, reptiles, and invertebrates are most sensitive to variations in habitat and are confined to smaller ranges.

Past Laboratory-wide information on the fauna within the Laboratory complex was largely qualitative; however, much quantitative information has been gathered in recent years in support of the biological assessment process. Biological assessments have been written for a great many projects and sampling activities throughout the Laboratory, but the assessments do not provide a comprehensive quantitative coverage of the entire Laboratory. Species lists have been compiled from observational

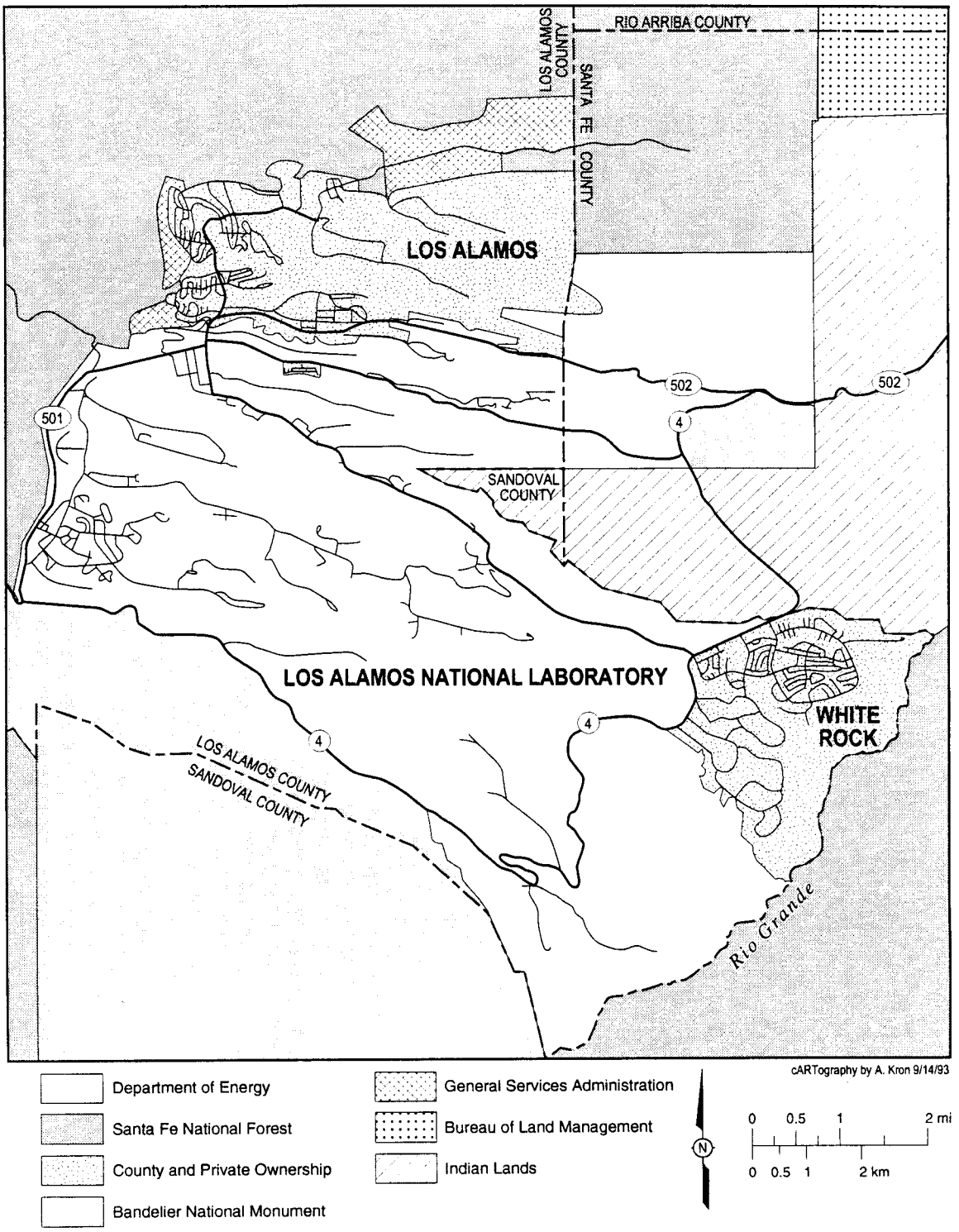

Figure 2-3. Land use map for the Laboratory and adjacent lands.

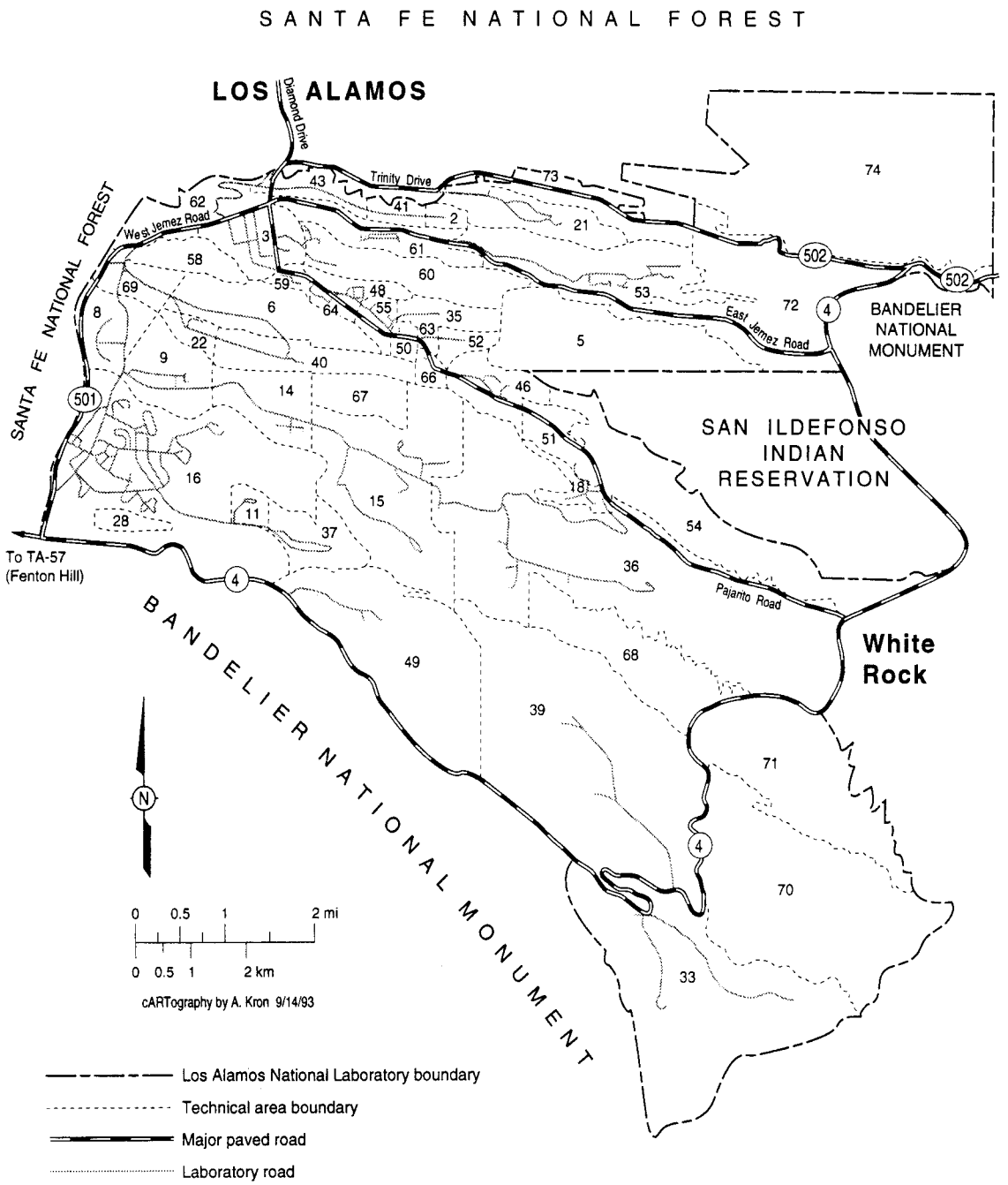

Figure 2-2. Technical areas at Los Alamos National Laboratory.

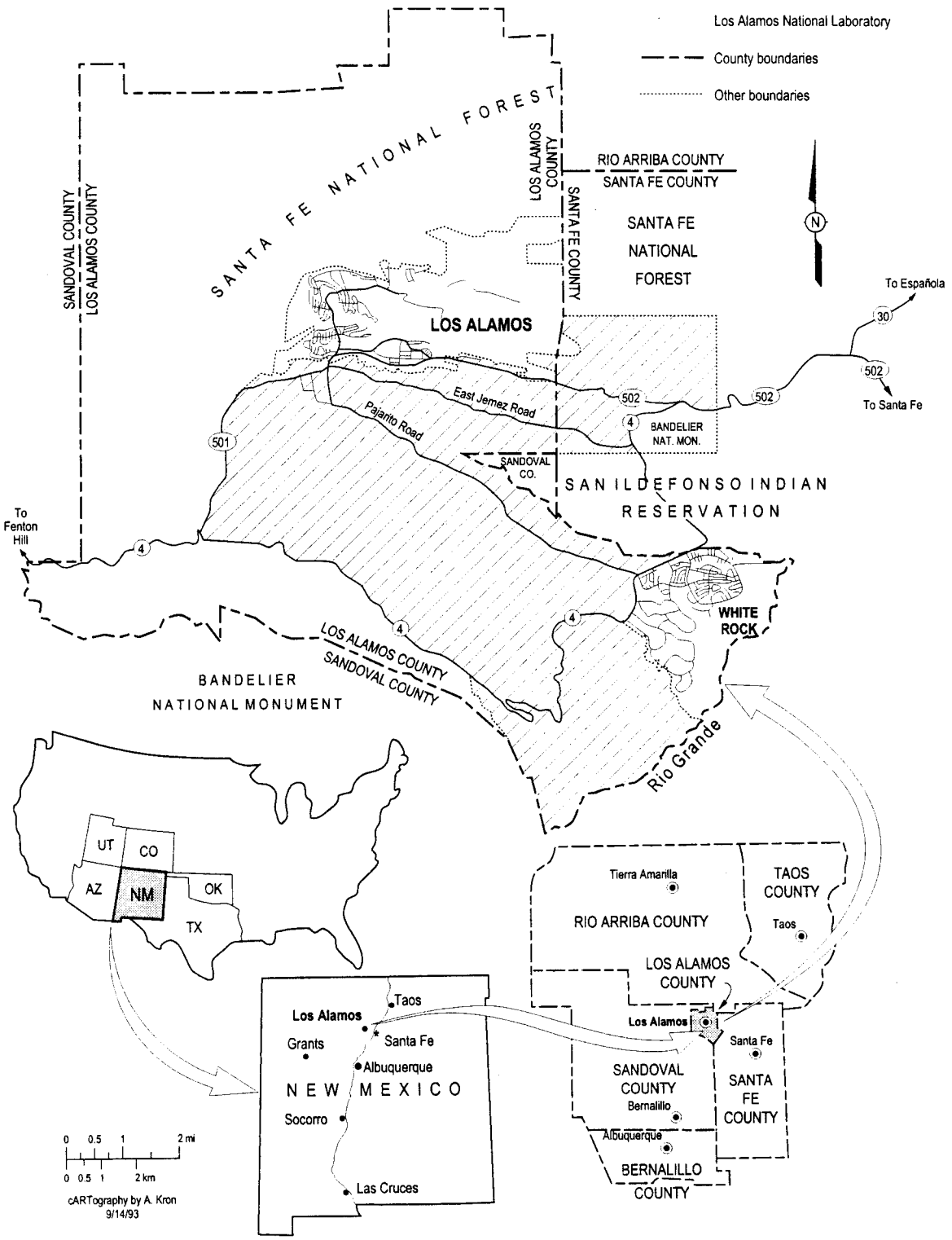

Figure 2-1. Location map of Los Alamos National Laboratory.

2.0 INSTALLATION DESCRIPTION

2.1 Geographic Setting

Los Alamos National Laboratory (the Laboratory) and the neighboring residential areas of Los Alamos and White Rock are located predominantly in Los Alamos County, north-central New Mexico, approximately 60 mi north-northeast of Albuquerque and 25 mi northwest of Santa Fe (Figure 2-1). The 43-mi^2 Laboratory site and the communities adjacent to it are situated on the Pajarito Plateau, which consists of a series of fingerlike mesas separated by deep canyons containing ephemeral and intermittent streams that run from west to east. Mesa tops range in elevation from approximately 7,800 ft on the flank of the Jemez Mountains to about 6,200 ft at their eastern termination above the Rio Grande valley. The eastern margin of the plateau stands 300 to 900 ft above the Rio Grande (DOE 1979, 8610). The Department of Energy (DOE) controls the area within the Laboratory's boundaries and determines restrictions on access.

2.2 History of Los Alamos National Laboratory

In 1942, the US Army Manhattan Engineer District was established to develop the atomic bomb. The research quickly progressed to a point that necessitated a remote site for experimental work, and the Army selected the Los Alamos Ranch School for Boys as an appropriate location. The Undersecretary of War directed acquisition of the school site, which consisted of a group of some 50 log buildings on a 790-acre site northwest of Santa Fe. The project ultimately acquired an additional 3,120 privately owned acres and 45,666 acres of public land managed by the US Forest Service. In 1943, this land became known as the Los Alamos Site, later Los Alamos Scientific Laboratory.

Since its inception, the Laboratory has been operated by University of California (UC) for the federal government. Research activities were established in wooden buildings south of the original Ranch School buildings in what is now downtown Los Alamos. Additional Laboratory buildings were constructed; army-style barracks, temporary and prefabricated, provided housing.

With the end of World War II and the growth of international competition, a national policy of maintaining superiority in the field of atomic energy was established. Congress chose to sustain the Los Alamos site; the Atomic Energy Commission (AEC) received control of the Laboratory from the Army and renewed the operating contract with UC. Thereafter, a major construction program was started south of Los Alamos Canyon. During subsequent years, the Laboratory continued to expand at a steady rate, first under the AEC and later under the Energy Research and Development Administration. Since 1978, the Laboratory has operated under the control of the DOE and is currently officially known as Los Alamos National Laboratory. A map showing active technical areas at the Laboratory is shown in Figure 2-2.

2.3 Environmental Setting

2.3.1 Land Use Patterns

Most Laboratory and community developments are confined to mesa tops. Large tracts of land north, west, and south of the Laboratory site are managed by the Santa Fe National Forest, Bureau of Land Management, Bandelier National Monument, General Services Administration, and Los Alamos County (Figure 2-3). The San Ildefonso Pueblo borders Los Alamos County and the Laboratory to the east.

whether contaminants migrate to deeper sections of the tuff or travel laterally to release areas on the mesa walls. All of these subsurface investigations should initially focus on the upper 100 to 200 ft of the vadose zone.

2.5.5.2 Migration of Moisture Beneath Canyon Bottoms

The canyons with alluvial perched groundwaters are presumed to present a greater potential for downward movement than do the mesa tops because there is a constant driving force and because the moisture content of the tuff below the saturated alluvium is significantly higher than that beneath the mesas. Additionally, the depth to the main aquifer in the canyons is several hundred feet less than from the adjacent mesa tops. The effect of this greater potential for fluid flow, though, is somewhat compensated by the general lack of highly concentrated contaminant sources in the canyon bottoms.

Recent investigations provide some important information on the movement of moisture and contaminants in the unsaturated tuff. The best field evidence that can be used to estimate potential downward rates of movement beneath canyon bottoms is obtained from corehole data collected by Stoker et al. (1991, 7530) in Mortandad Canyon. Because treated liquid radioactive effluents have been discharged to the canyon for almost 30 years, the radioactive constituents in effluent from the Laboratory serve as accurate tracers for fluid and contaminant migration studies.

The basic conclusions of the Mortandad study regarding the movement of radioactive contaminants below the alluvial perched groundwater are (1) soluble and particulate radioactive constituents have moved less than about 10 ft into the unsaturated zone beneath the alluvial perched groundwater and (2) tritium, as tritiated water, has moved at least 150 ft below the alluvial perched groundwater to a total depth of 195 ft. Tritium concentrations in Corehole MCM-5.9 (the deepest corehole drilled so far in the canyon) decrease by a factor of about 100 between 150 and 195 ft, suggesting the possibility that tritium has not moved much deeper in the almost 30 years since effluents were first released from the TA-50 treatment plant (Stoker et al. 1991, 7530). The tritium data suggest a downward rate of movement of at least 6 ft/yr. However, this conclusion must be considered tentative until additional, deeper coreholes can confirm the pattern.

Recent drilling of Characterization Well LADP-3 in Los Alamos Canyon has shown that Laboratory-derived tritium has migrated to depths of at least 330 ft beneath the canyon bottom (Broxton et al. 1995, 50119). Because the history of tritium releases to the canyon is uncertain, it is difficult to calculate a downward rate of contaminant movement at this location.

Stoker et al. (1991, 7530) evaluated the moisture content in tuff beneath the alluvial perched groundwater in Mortandad Canyon. Most values for gravimetric moisture content in the Tshirege Member beneath the alluvial perched groundwater ranged from 10% to 30%, corresponding to about 20% to 60% of saturation. Several peaks occurred at higher values, approaching 90% of saturation near the contact with or in the Tsankawi Pumice Bed and fluvial Cerro Toledo deposits on the top of the Otowi Member at depths around 100 ft. In the Otowi tuff, the gravimetric moisture content decreased and leveled off at about 12% to 18%, which corresponds to 20% to 40% saturation. A similar pattern occurred in a corehole farther downstream in Mortandad Canyon, past the end of the alluvial perched groundwater (Stoker et al. 1991, 7530), and also in Sandia and Potrillo Canyons (Environmental Protection Group 1993, 23249).

The data suggest that there are complex variations in hydrologic properties in the layers from the base of the Tshirege Member through to the top of the Otowi Member that significantly affect the movement of moisture in the unsaturated zone. There is also a suggestion that moisture conditions in the Otowi Member become very uniform, with only moderate differences in magnitude, depending on whether there are saturated conditions in overlying layers (Environmental Protection Group 1993, 23249). Additional field data and theoretical interpretation are required to confirm the patterns and quantify movement.

2.5.6 Groundwater Monitoring

The Laboratory has formulated a comprehensive groundwater protection plan (LANL 1995, 50124) for an enhanced set of characterization and monitoring activities. The Hydrogeologic Workplan (LANL 1996, 55430) details the implementation of extensive groundwater characterization across the Pajarito Plateau within an area potentially affected by Laboratory operations. The locations of the characterization wells and their proposed drilling and sampling plans address many areas of concern, in particular,

- delineating individual zones of saturation, and defining the hydraulic interconnection between them;
- delineating the recharge areas for the regional aquifer and intermediate perched zones;
- groundwater flow directions of the regional aquifer and intermediate perched zones, and the influence of resource withdrawal by production wells; and
- assessment of aquifer characteristics using the additional data from wells installed within specific intervals of the various aquifers beneath the Laboratory.

Installation of the boreholes and the information gained from them are coordinated with ongoing Environmental Restoration Project and environmental surveillance activities, including use of common resources and data collection/retrieval techniques. Installation of the 32 proposed boreholes is expected to commence in FY98 and continue through FY02; progress of this schedule is highly dependent on future funding.

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